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SATELLITE ORBIT DETERMINATION
A BIBLIOGRAPHY

by

Dale Denham

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U S ARMY MISSILE COMMAND
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Redstone Scientific Information Center
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ABSTRACT

The cited references pertain to the area of "Satellite Orbit Determination." This bibliography covers the following:

1) Methods to use and combine tracking data from radar and other tracking systems for orbit determination.

2) The influence of tracking station location, number of stations, and time of tracking on the accuracy of orbit determination.

In addition to the above, the cited references cover analysis and simulation of orbits; mathematics and parameters of orbits; theory and techniques; prediction and accuracies; programming and computers; error analysis; evaluation of ground coverage; systematic errors; airborne platforms; space dynamics; self-contained orbit determination techniques; and space-time.

This bibliography consists of four sections·

Section I - Introduction.

Section II - Orbit Determination, Entries 1 through 161.

Section III - Programs and Satellite Systems, Entries 162 through 187.

Section IV - Equipment and Facilities for Orbit Determination, Earth-Based, Entries 188 through 253.

FOREWORD

This bibliography consists of 253 entries concerning satellite orbits, tracking data, and equipment. Information sources for the period 1956 to May 1965 were searched. All entries are from the period of 1960 to 1965. Very little information could be found prior to 1960.

The entries were obtained from information sources available at the Redstone Scientific Information Center (RSIC). Searches were made of Engineering Indexes, International Aerospace Abstracts, Index Aeronautics, the Defense Documentation Center (DDC), and National Aeronautical and Space Administration (NASA) tape search which includes references on Scientific and Technical Aerospace Reports and International Aerospace Abstracts.

The references are arranged alphabetically either by corporate author or personal author, in each of the sections of this bibliography. Documents and papers are arranged by corporate author, and journal citations are arranged by personal author. Indexes for the following are included: personal author, Defense Documentation Center abstract number, International Aerospace abstract number, and corporate source report number.

TABLE OF CONTENTS

Section I. INTRODUCTION

Hundreds of abstracts were reviewed and only 253 were retained as entries in this bibliography. Because of the space effort during the past 5 years, many companies, universities, and government activities have been concerned with the orbits of satellites. The literature search revealed that considerable work had been performed in the United States of America, France, Russia, Germany, Great Britain, Sweden, Canada, Netherlands, Italy, Australia, and Taiwan.

This bibliography shows 300 authors from the 11 countries. Many of these authors, such as R. R. Allan and D. G. King-Hele of Great Britain, are quite well known.

The purpose of this bibliography is to provide abstracts concerning satellite orbit determination from tracking data. The literature search covered: (1) methods to use and combine tracking data from radar and other tracking systems for orbit determination; (2) the influence of tracking station location, number of stations, and time of tracking on the accuracy of orbit determination; (3) analytical and simulation studies of orbits; (4) mathematics and parameters of orbits; (5) theory and techniques of orbits; (6) prediction and accuracies of orbits; (7) programming and computers; (8) tracking systems; (9) missile ranges; (10) plans, experiments, and research requirements; (11) tracking station locations and number of stations; (12) type of tracking stations; (13) tracking methods; (14) analysis of multistation tracking methods; (15) optical trackers, techniques, and accuracies; (16) electronic trackers, techniques, and accuracies; (17) methods such as radiointerferential tracking, choosing optimum locations for tracking stations, linear combination of ranges and range rates, Doppler tracking, radar tracking, etc.; (18) data recording techniques; (19) trajectory monitor (real-time orbit determination); (20) capabilities and performance; (21) Laser and injection-Laser considerations for tracking; and (22) equipments.

Abstract (192) describes the simultaneous-lobing, amplitude-comparison, passive, CW tracker based in principle and design upon a monopulse tracking radar. Because the request for a literature search stated that the information was needed to support the development of the Airborne Range and Orbit Determination (AROD) System, a few abstracts cover airborne tracking systems, such as Russian discussion of a balloon-borne tracking system.

The DOPLOC Dark Satellite Tracking System (197) as well as many investigations such as "The Feasibility of Self-calibration of Tracking

Systems" are covered because of so many unknowns pertaining to satellite orbit determination from tracking data.

A current abstract (193) provides a world list of satellite tracking stations while another abstract (196) provides a general description of the role, logic operation, principles, and primary equipments of tracking stations. Abstract 208 provides a brief review of the different electronic tracking devices used for artificial satellites with both interferometer and radar tracking systems discussed, emphasizing the advantages of HF techniques.

Many abstracts cover the data recording techniques which show their application in the recording of data received from satellites.

This bibliography provides an abstract on the description of the ARIS (Integrated Instrumentation Radar) (211), a major subsystem of the first two Atlantic range instrumentation ships for the U. S. Air Force. The device uses a number of modern radar techniques to make accurate position and multifrequency target amplitude measurements on multiple high-speed targets located within its pencil beam. Both beacon and skin tracking are available.

A discussion of the current state-of-the-art of satellite tracking, emphasizing optical observation techniques and photographic tracking procedures and the precise determination of coordinates and of time is covered in this bibliography. Ballistic cameras as well as long-focal-length telescopes are discussed.

One excellent abstract (243) mentions a brief review of the factors involved in tracking-data acquisition. The effect of various errors on the technique used in determining the trajectory is considered, including the uncertainties in the speed of light, station location, and atmospheric density. It is seen that the unknowns in nature, and a lack of knowledge of the shape of the Earth, restrict the accuracy to which a satellite position can be predicted.

Derivation of equations which show how perigee distance and orbital period vary with eccentricity during the satellite's life, and how eccentricity is related to time is reported (75) by the English Scientist, D. G. King-Hele. Also, Helmut G. L. Krause of the Marshall Space Flight Center (NASA) made a study (81) on the extension of the special theory of relativity to include generalized relativistic conservation laws of momentum and total energy for bodies whose proper mass is variable with time - i. e., rockets.

At the American Institute of Aeronautics and Astronautics, Astrodynamics Conference, held at New Haven, Connecticut, August 1963, Merlin Dorfman presented a summary (40) of the derivation of general equations for evaluation of the accuracies of a satellite ephemeris generated from ground tracking data. He made reference to the full derivation, which considers the following error sources: (1) random observational errors; (2) data-bias uncertainties; (3) tracking-station-position uncertainties; (4) tracking-station clock errors; (5) tracking-station local coordinate uncertainties; (6) constant air-drag errors; (7) time-correlated air-drag fluctuations; and (8) gravitational uncertainties. It was shown that, if a weighted least squares fit is assumed, the error due to each source, for a given satellite and tracking plan, depends on a small number of parameters. The dependence of each error on these parameters was investigated in some detail. Total error was expressed as the root-sum-square of the error due to various sources. The effect on errors of allowing the orbit parameters to deviate somewhat from the basic one was investigated briefly.

Section II. ORBIT DETERMINATION

This section includes analytical and simulation studies of orbits, mathematics and parameters of orbits, theory and techniques of orbits, prediction and accuracies of orbits, and programming and computers.

1. Aeronutronic, Newport Beach, California, ASTRODYNAMIC RESEARCH AND COMPUTER PROGRAMS, January 1965, Report No. ESD-TDR-65-170, Contract No. AF 19(628)-3393, AD-612 156.

   The areas of liaison and direct support, on-site data processing, and space detection and tracking system (SPADATS) control center data processing are reported in response to the contract work statement.

2. Aeronutronic, Newport Beach, California, DIFFERENTIAL CORRECTION MODULE PROGRAM DOCUMENT, by J. R. Kuhlman and D. A. Craven, November 1964, Report No. ESD-TDR-64-660, Contract No. AF 19(628)-3393, AD-453 201.

   This report describes a computer program which represents and/or differentially corrects the orbit of an artificial Earth satellite. Statistical weighting of the observations is employed to account for the relative accuracy of the reporting sensors. The program uses either special or general perturbation techniques, as required, for ephemeris computations. The program description, formulation, operating instructions, flow diagrams, and test cases are included.

3. Aeronutronic, Newport Beach, California, INITIAL ORBIT DETERMINATION FROM LEAST SQUARES REDUCTION OF GEOCENTRIC POSITION VECTORS, by T. L. Johnston and T. P. Smith, January 1964, Report No. ESD-TDR-63-649, Contract No. AF 19(628)-562, AD-429 468.

   A computer program for initial orbit determination based on a theory employing a linear least squares fit to the geocentric position vectors was developed. Observations can be spread over a number of days since this procedure does not use the times of observations; however, they are used in the differential correction procedure. This program, coded for the Philco 2000, is designed for operational use at the Space Detection and Tracking Center in Colorado Springs, Colorado.

4. Aeronutronic, Newport Beach, California,
LOOK ANGLE MODULE PROGRAM DOCUMENT, by R. W. Day and G. A. Mahon, January 1965, Report No. ESD-TDR-65-77, Contract No. AF 19(628)-3393, AD-457 121.

A computer program has been developed to calculate acquisition coordinates of Earth satellites of all inclinations and elliptic eccentricities for the following types of sensors: optical, conventional tracking, conical fan, planar fan, and phased array tracking. This program, coded for the Philco 2000 and designed for operation in the SPADATS B-2 system, may be used to generate sensor-satellite or satellite-sensor look angle patterns for satellites and sensors presented to the system through standardized inputs and/or storage files.

5. Aerospace Corporation, Los Angeles, California,
ACQUISITION OF ADVENT SATELLITE BY TT AND C STATIONS, by Cameron Jones, May 1962, Report No. TOR-69(2109)-14, Contract No. AF 04(695)-69, AD-445 408.

This document defines assistance required by advent TT and C stations to assure acquisition of advent satellites. A number of acquisition situations were studied and conclusions are presented. The conclusions are discussed and justified, and recommendations are presented. Data used to arrive at the conclusions and recommendations are included in the appendices with explanations of their significance or appropriate reference material.

6. Aerospace Corporation, Los Angeles, California,
DATA ACQUISITION, HANDLING, AND EVALUATION, PROJECT TRANSIT 4-B, November 1961, Report No. TOR-930(2102)-5, Contract No. AF 04(647)-930, AD-448 092.

This report presents plans and procedures to be used for the acquisition, transmission, and analysis of the launch phase, and orbit data for the THOR/ABLESTAR vehicle used on the transit 4-B mission. Data accumulated by these methods will be utilized in evaluating the flight test objectives under the cognizance of the U. S. Air Force Space Systems Division and its associate contractors.

7. Aerospace Corporation, Los Angeles, California,
METHODS FOR OPTIMIZING RADAR STATION LOCATIONS IN RELATION TO SATELLITE TRACKING, by A. S. Mager, August 1963, Report No. SSD-TDR-63-246, Contract No. AF 04(695)-169, AD-422 671.

Two methods were derived to aid in optimizing satellite tracking station locations. These methods are: Method I-Determines the percentage of time a satellite is within range of a ground tracking station; Method II-Determines the number of satellite sightings made per day by a ground tracking station. Both of these methods can be expanded to determine the locations of stations for best over-all coverage if the frequency distribution of future satellite orbit inclinations is known.

8. Aerospace Corporation, Los Angeles, California,
ORBIT DETERMINATION ERROR ANALYSIS, by D. R. Peece, August 1963, Report No. SSD-TDR-63-201, AD-419 467.

The problem of orbit determination by radar tracking data is broken into its constituent parts, which are then subjected to detailed examination. Typical results are presented and discussed as a method of arriving at general conclusions. The behavior of orbital errors is interpreted in terms of the influence of their sources and the nature of their propagation. The emphasis of this analysis is on why orbital errors behave as they do, how well can we expect to determine orbits, and how can we do better. The conclusions are based on the results of a large number of digital simulations with the Aerospace Trace program and the General Electric PAT-B program, plus limited experience in the reduction of "live" data from the SCF net.

9. Aerospace Corporation, Los Angeles, California,
TRACE, AEROSPACE ORBIT DETERMINATION PROGRAM, by R. J. Mercer, November 1964, Report No. SSD-TDR-64-159, Contract No. AF 04(695)-269, AD-454 404.

Trace is a multiple-purpose satellite orbit determination program for the IBM 7090 computer. The program applications include: (1) PREDICTION-The generation of a satellite trajectory and associated ground trace and station sighting data; (2) ORBIT DETERMINATION-Estimation of trajectory parameters, station locations, and observational biases, so as to best fit a set of observations; and (3) ERROR ANALYSIS-Estimation of the potential accuracy attainable by a tracking system, given the station locations, the data types, rates and quality, the uncertainties in the model parameters, and the specifications of the nominal orbit. The report contains the objectives of the program, some theoretical foundations, the equations and methods employed, the structure of the program, and complete instructions for the program's use.

10. Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio,
A METHOD FOR DETERMINING THE EFFECT OF DYNAMIC ERRORS OF A RADAR SATELLITE TRACKER ON ORBIT PREDICTION, by Thomas Henry McMullen, August 1964, Master's Thesis, AD-607 031.

This thesis briefly discusses the difficulty of specifying the accuracy of a satellite tracker. Equations are developed which: (1) determine azimuth and elevation angle data and fit them to fourth order time polynomials; (2) compute the orbit parameters from evaluations of these polynomials; and (3) evaluate the response of a selected tracker transfer function to the input of these time polynomials by the method of Laplace transformation. Orbit elements computed from this last evaluation are compared with the previous set to obtain the error in orbit prediction. A FORTRAN II program is presented which performs these computations on the IBM 7094 digital computer.

11. Akim, E. L. and Eneev, T. M.,
DETERMINATION OF THE FLIGHT PARAMETERS OF A SPACE VEHICLE FROM TRAJECTORY DATA (OPREDELENIE PARAMETROV DVIZHENILA KOSMICHESKOGO LETATEL'NOGO APPARATA NO DANNYM TRAEKTORNYKH IZMERENII), Kosmicheskie Issledovaniia, Vol. 1, No. 1, pp. 5-50, July-August 1963, A63-22821 (In Russian).

This is a presentation of a method for the determination of vehicle orbits on high-speed universal computers. Computational accuracy and speed are achieved by use of relatively simple algorithms and computational schemes which take into account the specific peculiarities of the force field and the vehicle's flight dynamics in this field. Included are a scheme for breaking up the trajectory into sections of slightly disturbed motion, a scheme for selecting orbital parameters suitable for any orbit, and a model and formulas for the calculation of the partial derivatives. An algorithm for evaluating the accuracy of vehicle motion, predicted from the processed trajectory data, is also derived. The method of minimum-time descent, and the calculation of the velocity of a point from orbital elements are discussed in appendices.

12. Alippi, Carlo,
IL PENDOLO DI SCHULER E I PERIODI ORBITALI, Missili, Vol. 4, pp. 5-8, February 1962, A62-7388 (In Italian).

This is a discussion of the relationship between the period of a Schuler (Earth) pendulum and that of an Earth satellite. The orbital period of a low-altitude satellite will be approximately the same as the period of a Schuler Pendulum, expressed by the formula $T = 2\pi\sqrt{r/g}$ - i.e., 84.4 minutes. The periods of (1) the Titov flight in Vostok II (88.1 minutes) and (2) an equatorial orbit (89.6 minutes) are noted, and the differences between these and the Schuler-pendulum period are discussed briefly.

13. Allan, R. R.,
ON THE DRIFT OF SYNCOM 2 AND THE VALUE OF $J_{2,2}$, Planetary and Space Science, Vol. 12, pp. 283-285, April 1964, A64-18206.

This is a study of data concerning the drift of Syncom 2 (1963 31A) and a presentation of an expression for the longitudinal drift acceleration of this satellite. Neglecting lunar and solar perturbations, an expression for the longitudinal drift acceleration is presented that considers only the (2, 2) tesseral harmonic of the Bessel type. The coefficient of this harmonic is plotted as a function of the assumed longitude of the major axis of the Earth's equatorial section that corresponds to it. Although this graph is consistent with Guier's results, deduced from Doppler data, it is implied that a better description of the motion requires a more complete set of coefficients of the tesseral harmonic.

14. Allan, R. R.,
SATELLITE ORBIT PERTURBATIONS IN VECTOR FORM, Nature, Vol. 190, p. 615, 13 May 1961, A61-5848.

This article presents a formulation of the first-order perturbation theory of satellite orbits in terms of constants of the unperturbed motion, using vector methods.

15. Bailie, A. and Bryant, R.,
OSCULATING ELEMENTS DERIVED FROM THE MODIFIED HANSEN'S THEORY FOR THE MOTION OF AN ARTIFICIAL SATELLITE, U. S., NASA TN D-568, 8pp., January 1961, A61-2801.

This is an application of the modified Hansen theory, which heretofore gave only the position vector of the satellite, to derive the velocity vector and the osculating elements. The modified Hansen theory represents the gravitational perturbations of an artificial satellite. The development takes the form of several trigonometric series with numerical coefficients and specified arguments. The position vector of the satellite is determined by evaluating these series, and in turn, it is shown how the velocity vector and the osculating elements can be derived from this theory. This significant adjunct to Hansen's theory permits comparison with other general perturbation theories and with special perturbation techniques. Accurate transition from the general theory to numerical integration makes it possible to transfer to the latter method when additional disturbing forces not included in the general theory become of consequence.

16. Baker, Robert M. L., Jr.,
THE ELIMINATION OF SPURIOUS DATA IN THE PROCESS OF PRELIMINARY AND DEFINITIVE ORBIT DETERMINATION, in Dynamics of Satellites, Proceedings of the IUTAM Symposium, Paris, France, 28-30 May 1962, New York, Academic Press, Incorporated, 1963, pp. 1-13, A64-12655.

This presents a brief summary of early procedures for processing Minitrack, pulsed-radar, and Baker-Nunn camera data, for preliminary orbit determination. A more novel method, employing high-accuracy, range-rate data together with low accuracy, angle data, is also presented, and its application to a recent Ranger lunar probe orbit, as observed by Goldstone, is noted. The process of eliminating spurious observational data on the basis of these preliminary orbits and through the use of a filtering technique is considered in detail. The potential advantages of the Gibbsian method for correlating observed data are also noted.

17. Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland,
ORBITAL DATA HANDLING AND PRESENTATION, by R. E. A. Putnam, June 1959, Report No. BRL-TN-No. 1265, AD-419 363.

The problem of detecting dark (passive) satellites, utilizing Doppler techniques, is accompanied by a need for early satellite identification. . The latter requirement necessitates an expeditious handling and classification of orbital data, and a presentation of results in ways that facilitate positive and immediate identification of "strange" satellites. The result of a preliminary study of prospective data handling and presentation procedures is presented. Its purpose is to present the relative merits and limitations of various alternatives proposed, to indicate the particular methods worthy of serious consideration and further study, and to outline the time factors and development costs likely to be involved in procuring prototype equipment. Discussion is limited to a general, rather than to a specific treatment of the subject, because numerous pertinent details of instrumentation and orbital computation procedures are currently in a state of flux.

18. Bandeen, W. R.,
EARTH OBLATENESS AND RELATIVE SUN MOTION CONSIDERATIONS IN THE DETERMINATION OF AN IDEAL ORBIT FOR THE NIMBUS METEOROLOGICAL SATELLITE, U. S., NASA TN D-1045, 12 pp. July 1961, A61-7799.

This article presents an application of the phenomenon of nodal regression to the determination of the ideal orbit for a satellite which is required to cross the equator at local noon and, half an orbit later, cross the equator in the opposite direction at local midnight. Angles of inclination, periods, and heights of such "ideal" orbits are analyzed, and the relative motion of the apparent versus the fictitious mean sun is discussed briefly.

19. Barrar, R. B. and Deutsch, R.,
DETERMINATION OF SATELLITE TRAJECTORIES FROM TRACK-WHILE-SCAN RADAR MEASUREMENTS, IRE Transactions, Military Electronics, Vol. MIL-5, pp. 306-311, October 1961, A62-2061.

This article is a presentation of three approximate methods for the determination of satellite orbits from track-while-scan radar observations. The methods, which avoid the necessity of the solution of transcendental equations, are founded upon dynamic principles rather than numerical approximations, and are based upon a method of Gibbs. The accuracy of orbit determination by these techniques is demonstrated by the numerical evaluation of some typical cases.

20. Batrakov, V.,
PERTURBATIONS IN THE MOTION OF A SATELLITE DUE TO THE SECOND ZONAL HARMONIC OF THE EARTH'S POTENTIAL, in Dynamics of Satellites, Proceedings of the IUTAM Symposium, Paris, France, 28-30 May 1962, New York, Academic Press, Incorporated, 1963, pp. 74-82, A64-12662 (Translation).

This article presents a calculation up to the terms of order e_0^2, of the secular perturbations of the second order and long periodic perturbations of the first order in the orbital elements of Earth's satellites due to the second zonal harmonic of the gravitational potential of the Earth. The short periodic perturbations are given up to the terms with e_0^5. The results of this study and those of Brouwer appear to be identical with the assumed accuracy, provided the difference in constants of integration is taken into account.

21. Bergqvist, Björn,
JORDSATELLITBANOR, Teknisk Tidskrift, Vol. 90, pp. 1161-1166, 18 November 1960, A61-7784 (In Swedish).

This article contains a discussion of orbit mechanics of unmanned artificial earth satellites, covering the types of ascent and descent trajectories, as well as the effect of various terrestrial factors such as the density of the atmosphere, the rotation of the earth, and the launching latitude.

22. Blackman, R. B.,
METHODS OF ORBIT REFINEMENT, Bell System Technical Journal, Vol. 43, pp. 885-909, May 1964, A64-19288.

This article contains a description of several methods of orbit refinement which were developed specifically for use with artificial satellites and spacecraft during the past 6 or 7 years. Also described is the classical method, in a uniform mathematical formalism, in order to facilitate comparisons of their relative advantages and disadvantages for practical systems applications. It is pointed out, however, that such comparisons are made only to the extent that they motivated the development of the new methods.

23. Bodwell, C. A.,
A WEIGHTED LEAST-SQUARES DETERMINATION OF THE UNPERTURBED ORBITAL ELEMENTS WHICH COMBINES VARIOUS TYPES OF OBSERVATIONAL DATA. Appendix A - ROTATION MATRIX AND DERIVATIVES FOR ROTATING FROM THE ORBITAL PLANE COORDINATE SYSTEM TO THE INERTIAL COORDINATE SYSTEM. Appendix B - ROTATION MATRIX AND DERIVATIVES FOR ROTATING FROM THE LOCAL HORIZON COORDINATE SYSTEM TO THE INERTIAL COORDINATE SYSTEM. Appendix C - INERTIAL COORDINATES OF A POINT AS A FUNCTION OF THE ELLIPTICAL ELEMENTS DEFINING THE OBLATE SPHEROID OF THE IDEALIZED EARTH, SIDEREAL TIME, AND THE GEODETIC LATITUDE, LONGITUDE, AND HEIGHT OF THE POINT ABOVE THE SPHEROID. Appendix D - MACHINE METHOD FOR THE DETERMINATION OF SIDEREAL TIME. Appendix E - PARTIAL DERIVATIVES NEEDED IN THE LINEARIZATION PROCESS. Appendix F - INITIAL ESTIMATES OF THE ORBITAL ELEMENTS AS OBTAINED FROM RANGE, AZIMUTH, AND ELEVATION DATA, USAF, Missile Development Center, Holloman Air Force Base, New Mexico, TR 61-2, 103 pp., March 1961, A61-7782.

This report is a presentation of a method for using almost any combination of number and type of observations from any number of observational sites in determining: (1) the weighted least-squares unperturbed orbital elements of a satellite or an ICBM; (2) whether the data are indicative of a satellite or an ICBM; (3) the ground trace and height of the trajectory with respect to any desired ellipsoid of revolution; and (4) the apparent velocity vector of the missile with respect to any given local horizon coordinate system. In the case of an ICBM, the procedure for determining the times and locations of the unperturbed launch and impact point is given. The procedure does not make use of numerical integration.

24. Boehm, Barry,
PROBABILISTIC EVALUATION OF SATELLITE MISSIONS INVOLVING GROUND COVERAGE, American Institute of Aeronautics and Astronautics, Astrodynamics, Conference, New Haven, Connecticut, Paper 63-396, 10 pp., 19-21 August 1965, A63-21712.

A relation P(α , s, h, i) is developed for the probability of occurrence of the following event: that a point Q on Earth at latitude α comes within a distance s of the ground track of a satellite in orbit at an altitude h and an inclination i, during a single satellite orbital revolution, under the assumption that the point Q is randomly located in longitude with respect to the ascending node of the orbit. Some methods of using the relation to evaluate coverage capabilities of satellite systems are presented.

25. Bonavito, N. L.,
COMPUTATIONAL PROCEDURE FOR VINTI'S THEORY OF AN ACCURATE INTERMEDIARY ORBIT, U. S., NASA TN D-1177, 26 pp., March 1962, A62-5328.

This report contains a description of a procedure for the computation of the coordinates and velocity of an unretarded satellite from a knowledge of its initial conditions. By the introduction of the oblate spheroidal system of generalized coordinates into the solution of Laplace's equation, three adjustable constants are provided, by means of which this solution can be made to agree largely with the Earth's potential expressed as a general expansion in spherical harmonics. The agreement is exact for the zero, first, and second zonal harmonics - and, consequently, through more than half of the latest accepted value of the Earth's fourth harmonic.

26. Cassara, Phillip P.,
THE INFLUENCE OF TESSERAL HARMONICS AND LUNISOLAR GRAVITATION OF THE MOTION OF A 24-HOUR SATELLITE, American Institute of Aeronautics and Astronautics, Summer Meeting, Los Angeles, California, Paper 63-153, 15 pp., 17-20 June 1963, A63-18743.

This article is an analysis of the problem of predicting the motion of a 24-hour satellite under the influence of the gravitational fields of the Earth, Sun, and Moon, using five different Earth gravity models and tabulated ephemerides of the Sun and Moon. The Earth potential function is represented by a series of zonal, tesseral, and sectorial harmonics truncated to the fourth order. These are incorporated into equations of motion derived from the Lagrange equations formulated in geocentric, Earth-fixed, spherical coordinates. The equations of motion are solved numerically. It is shown that (1) the

satellite exhibits a combination of diurnal oscillations induced by the lunisolar potential, and a long-period libration about the closest "stable point" due to the tesseral and sectorial harmonics in the Earth potential; (2) the number and/or positions of the stable points (and, therefore, of the librations of the satellite) are sensitive to the values assigned to the coefficients of the tesseral and sectorial harmonics; and (3) the lunisolar effect is negligible except when the satellite is stationed close to a stable point.

27. Chebotarev, G. A.,
MOTION OF AN ARTIFICIAL EARTH SATELLITE IN AN ORBIT OF SMALL ECCENTRICITY, (Institut Teoreticheskoi Astronomii, Bulleten', Vol. 2, No. 1, pp. 1-10, 1963), AIAA Journal, Russian Supplement, Vol. 2, pp. 203-208, January 1964, A64-13193 (Translation).

This article contains a calculation of perturbations of the elements of near-circular Earth satellite orbits. Literal expressions are found for calculating first-order perturbations to an accuracy of the order of and including the first power of eccentricity. The improvement of the elements of near-circular orbits is also discussed. Determination of the constants of integration is considered.

28. Claus, A. J.; Blackman, R. B.; Halline, E. G.; and Ridgeway, W. C., III;
ORBIT DETERMINATION AND PREDICTION, AND COMPUTER PROGRAMS, Bell System Technical Journal, Vol. 42, Pt. 2, pp. 1357-1382, July 1963, A63-22480.

This article contains a description of the methods and programs used in the Telstar project for the purposes of orbit determination and ephemeris calculation. The orbit determination process involves the computation of orbital elements from tracking data obtained during each pass, and subsequent refinement by combining such single-pass estimates. The tracking data are in terms of angular observations.

29. Claus, A. J.,
ORBIT DETERMINATION IN THE PRESENCE OF SYSTEMATIC ERRORS, in Celestial Mechanics and Astrodynamics (Progress in Astronautics and Aeronautics Vol. 14), New York, Academic Press, Incorporated, 1964, pp. 725-742, A64-26221.

This is a presentation of a method for orbit refinement from tracking data. The data are assumed to contain random errors, as well as errors that can be expressed in some known functional form but involving unknown constants. These assumptions are shown to lead to a smoothing technique capable of producing orbital elements with a minimum sensitivy to systematic errors. The formulas are derived explicitly in the case in which the only systematic errors present are constant throughout the visibility zone of the pertinent observer. The hypothetical case in which no random errors appear is treated in some detail. One possible way of implementing the method on an electronic computer is discussed briefly and indicates that only minor modifications are required of more conventional computer routines where the presence of systematic errors is ignored completely.

30. Cole, K. D.,
ORBITAL ACCELERATION OF SATELLITES DURING GEO-MAGNETIC DISTURBANCE, Nature, Vol. 194, pp. 42 and 75, 7 April 1962, A62-6342.

This article is an analysis of the possibility that Joule heating of the upper atmosphere is responsible for observed fluctuations in the orbital acceleration of artificial Earth satellites with geomagnetic disturbance. It is concluded that Joule heating of the lower ionosphere, at altitudes of 100-250 kilometers, is a major factor in the modulation of thermospheric densities.

31. Cook, G. E.,
EFFECT OF AN OBLATE, ROTATING ATMOSPHERE ON THE ORIENTATION OF A SATELLITE ORBIT, Great Britain, RAE, G. W. 550, 27 pp., June 1960, A61-1307.

This article contains a study considering a satellite orbit of small eccentricity ($e < 0.2$), for which formulas are derived for the changes per revolution produced by the atmosphere in the argument of perigee, in the right ascension of the ascending node, and in the orbital inclination. These changes are then expressed in terms of the change in length of the semi-major axis, and numerical values are obtained for satellite 1957β. It is found that the rotation of the major axis in the orbital phase due to the atmosphere is significant, being most important for inclinations between 60 and 70 degrees. The total rotation, due both to the gravitational potential and to the atmosphere, agrees reasonably with the observed values. The oblateness of the atmosphere is found to have only a small effect on the change in the orbital inclination and the right ascension of the ascending node.

32. Cook, G. E.,
LUNI-SOLAR PERTURBATIONS OF THE ORBIT OF AN EARTH SATELLITE, Great Britain, RAE, TN G. W. 582, 37 pp., July 1961, A62-1000.

This article contains an analysis, using the Lagrange planetary equations, of the effect of solar and lunar gravitational attraction upon the orbital elements of a terrestrial satellite. Expressions are obtained for the change in the elements during one revolution of the satellite, and for the rates of change of these elements. Corresponding expressions are obtained for the effects of solar radiation pressure, the effect of the Earth's shadow being included.

33. Cook, G. E. and King-Hele, D. G.,
THE CONTRACTION OF SATELLITE ORBITS UNDER THE INFLUENCE OF AIR DRAG. IV - WITH SCALE HEIGHT DEPENDENT ON ALTITUDE, Royal Society, London, England, Proceedings, Series A, Vol. 275, pp. 357-390, 8 October 1963, A64-11155.

This article is an extension of a previous analysis of the effect of air drag on satellite orbits of small eccentricity to the case in which the density scale height of the atmosphere, H, varies linearly with the distance from the Earth's center. Equations are derived which show how perigee distance and orbital period vary with eccentricity, and how eccentricity varies with time. Expressions are also obtained for the lifetime and air density at perigee in terms of the rate of change or orbital period. The main results are presented graphically. The results are formulated in two ways. The first method is to specify the extra terms to be added to the constant-H equations of Part I. The second (and usually better) method is to obtain the best constant value of H for use with the equations of Part I. For example, it is found that the constant-H equations connecting perigee distance (or orbital period) and eccentricity can be used unchanged without loss in accuracy, if H is taken as the value of the variable H at a height γ H above the mean perigee height during the time interval being considered, where $\gamma = 3/2$ for $e > 0.02$, and γ decreases from 3/2 towards zero as e decreases from 0.02 towards 0.

34. Cook, G. E. and Plimmer, R. N. A.,
THE EFFECT OF ATMOSPHERIC ROTATION ON THE ORBITAL PLANE OF A NEAR-EARTH SATELLITE, Royal Society, London, England, Proceedings, Series A, Vol. 258, pp. 516-528, 8 November 1960, A61-550.

This article contains a derivation of formulas for the rotation of the orbital plane about the Earth's axis and the change in orbital inclination of a near-earth satellite of small eccentricity (< 0.2) due to the influence of the atmosphere. It is assumed that the atmosphere is spherically symmetrical and has a density which varies exponentially with altitude. Comparison of the theoretical changes in orbital inclination show reasonably good agreement with those estimated from kinetheodolite observations, although the need for a slightly steeper theoretical curve is indicated. Although the rotation of the orbital plane is small, allowance must be made for it when making estimates of the harmonic of the Earth's gravitational field.

35. Cornford, E. C.; King-Hele, D. G.; and Merson, R. H.;
RECENT STUDIES OF SATELLITE ORBITS, in Seventh Anglo-American Aeronautical Conference, New York, 5-7 October 1959, Convened by the IAS, RAeS, and CAI. New York, IAS, pp. 34-65, 1960, A61-2023.

Not abstracted.

36. Crane, J. A.,
ON THE MOTION OF A PARTICLE ABOUT AN OBLATE SPHEROID. III - PARABOLIC AND HIGHLY ELLIPTIC ORBITS, British Interplanetary Society Journal, Vol. 17, pp. 437-440, November-December 1960, A61-2022.

This article is a presentation of a new approach which uses the method of the variations of elements and which widens the application of this method. Two orbital elements, the radial distance at perigee and the semilatus rectum, are introduced to replace the usual semimajor axis and eccentricity for parabolic and highly elliptic orbits. The solution of the motion of a particle about an oblate spheroid in a vacuum is then derived, using the new elements, by means of the method of the variation of elements.

37. Crickmay, C. J.,
OPTIMIZING THE GEOGRAPHICAL LOCATION OF SATELLITE TRACKING STATIONS, ARS Journal, Vol. 32, pp. 107-113, January 1962, A62-3072.

This article contains a development of a method of determining the location of satellite tracking stations in order to obtain the maximum trajectory visibility time. Familiar expressions for Earth projection of a circular satellite orbit are presented. A technique for computing the visibility limit curves for a ground tracking station is indicated. Typical examples of all computations are shown, as well as maps of visibility contours for a number of ground stations in a world-wide tracking network.

38. Danby, J. M. A.,
MATRIX METHODS IN THE CALCULATION AND ANALYSIS OF ORBITS, AIAA Journal, Vol. 2, pp. 13-16, January 1964, A64-13122.

This article is a presentation of formulas for the calculation of special perturbations using matrix methods that have been formerly adapted to problems of general perturbations. The practical application of these formulas to the case of a circumlunar orbit is described. It is shown that once calculated, the results for the orbit are in such a form that its analysis (error analysis and guidance) can be carried out with the use of simple closed functions without further integration.

39. Dobbie, James M.,
SEARCH THEORY - A SEQUENTIAL APPROACH, Naval Research Logistics Quarterly, Vol. 10, pp. 323-334, December 1963, A64-18902.

This article is a presentation of a procedure for determining the optimal distributions of effort to maximize the detection probability with a given effort. In this procedure the optimal distribution has the property that it is the sum of the distributions obtained by optimizing conditionally when the effort is applied sequentially. It is shown that this method yields essentially all of the known results, both for the discrete and continuous cases, and for the two criteria of maximizing the detection probability with a given effort and minimizing the expected effort to attain a given attainable probability of detection. The method also yields some extensions. In the discrete case, the method is equivalent to the simplest form of dynamic programming.

40. Dorfman, Merlin and Maxwell, James A.,
SOME RESULTS OF A STUDY OF ORBIT DETERMINATION ACCURACIES, American Institute of Aeronautics and Astronautics, Astrodynamics Conference, New Haven, Connecticut, Paper 63-432, 16 pp. 19-21 August 1963, A63-20653.

This article is a summary of the derivation of general equations for evaluation of the accuracy of a satellite ephemeris generated from ground tracking data. Reference is made to the full derivation, which considers the following error sources: (1) random observational errors, (2) data-bias uncertainties, (3) tracking-station-position uncertainties, (4) tracking-station-clock errors, (5) tracking-station local coordinate uncertainties, (6) constant air-drag errors, (7) time-correlated air-drag fluctuations, and (8) gravitational uncertainties. It is shown that, if a weighted least squares fit is assumed, the error due to each source, for a given satellite and tracking plan, depends on a very small number of parameters. The dependence of each error on these parameters is investigated in some detail. Total error can then be expressed as the root-sum-square of the error due to the various sources. The effect on errors of allowing the orbit parameters to deviate somewhat from the basic one is investigated briefly.

41. Ducrocq, Albert,
VERS DES ORBITES STABLES? L'Air et l'Espace, pp. 44-49, January 1961, A61-5856 (In French).

This article is a discussion of the degradation of the orbits of artificial satellites which at perigee pass through a relatively dense part of the upper atmosphere, of the problem this poses for projected satellite communications systems, and of the possibility of achieving orbits of indefinite life. The extent of the Earth's atmosphere is considered, and it is noted that (although all such limits are relative) a minimum altitude of 3000 kilometers at perigee would be necessary for a stable orbit. Experience with the Echo I balloon satellite is reviewed, and factors affecting satellite orbits are discussed, including the laws of celestial mechanics, the gravitational field of the Earth (taking into account the Earth's asymmetry), and that of other planets. The system used in the Transit program (observation by the Minitrack network and prediction of the satellite's position by associated computers) is noted. Another solution to the problem, the use of equatorial orbits, is discussed at some length, particularly in relation to a 'stationary' satellite.

42. Easterling, Mahlon F.,
APPLICATIONS TO RANGING, in DIGITAL COMMUNICATIONS WITH SPACE APPLICATIONS, Englewood Cliffs, New Jersey, Prentice-Hall, Incorporated, 1964, pp. 85-105, A65-14584.

This is a discussion of techniques that have been developed and applied in operational ranging systems to use waves coded by sequences having multiple peaks in their autocorrelation functions. The waves used are either binary waveforms or are modulated by binary waveforms; binary waveforms used for ranging are called ranging codes or acquirable codes. Topics covered are: correlation and tracking schemes, acquirable codes, ranging receivers, and acquisition time for a ranging code. Examples are given of calculations of the acquisition time for the ranging code for systems suitable for satellites in Earth orbit, for lunar probes, and for planetary probes.

43. Eggleston, J. M. and Beck, H. D.
A STUDY OF THE POSITIONS AND VELOCITIES OF A SPACE STATION AND A ~~FERRY VEHICLE~~ DURING RENDEZVOUS AND RETURN. Appendix A - EQUATIONS OF MOTION OF A MASS AS MEASURED IN A ROTATING FRAME OF AXES WHICH FOLLOWS A KEPLERIAN TRAJECTORY. Appendix B - EQUATIONS OF MOTION AND APPROXIMATE SOLUTIONS TO THE MOTION OF A MASS AS MEASURED IN A ROTATING FRAME OF AXES WHICH MOVES IN A CIRCULAR ORBIT. Appendix C - POSITION AND VELOCITY OF FERRY WITH RESPECT TO EARTH-FIXED COORDINATE SYSTEM. Appen-dex D - ANALYTICAL CALCULATION OF BOUNDARIES OF LAUNCH AND RENDEZVOUS CONDITIONS, U. S., NASA TR R-87, 82 pp., 1961, A61-1991.

This is a study dealing with the families of nonthrusting ascent trajectories of a ferry vehicle during rendezvous with an orbiting body, referred to as a space station. It is shown that these trajectories may be interpreted as descent trajectories of the ferry from the station to the earth. Equations of motion are derived and results are shown for two typical orbits of the station (one circular and one elliptic orbit). Trajectories are described in terms of a rotating coordinate system fixed in the station, and launch conditions are tabulated in terms of nonrotating inertial coordinates. Boundaries of launch (at time of booster burnout) and rendezvous conditions are presented, and the effects of delays in launch time are discussed.

44. Electronic Defense Laboratory, Mountain View, California,
A TWO-BODY PROGRAM FOR THE SIMULATION OF BALLISTIC-MISSILE AND EARTH-SATELLITE MOTION, by Richard D. Bauman, August 1964, Report No. EDL-M-717, AD-458 400.

This report states that the two-body assumption provides the basis for a useful approximation to the motion of earth satellites and ballistic missiles. A computer program has been developed to implement the two-body equations. The theory and operation of the program are described in detail. The program can accept data in various forms. The solution of the two-body equations is then accomplished by an extremely concise vector technique. The output of the program can be varied so as to include such information as ground tracking, vehicle orientation angles, observer tracking data, tracking rates, and atmospheric refraction corrections. A listing of the program and complete operating instructions are included.

45. Electronic Systems Division, Air Force Systems Command, Bedford, Massachusetts,
AIRBORNE INSTRUMENTATION PLATFORM FEASIBILITY STUDY RESULTS, January 1964, Report No. ESD-TDR-64-182, AD-427 827.

The results of a feasibility study to determine the utility of an airborne instrumentation platform for making tracking measurements on satellite and spacecraft trajectories are presented. This report considers an analysis of the capability of a system, to be developed through the integration of state-of-the-art sensor (radar and optical), communication, navigation, data processing, and telemetry equipment to satisfy the tracking measurement requirements of typical orbital profiles.

46. Electronics Systems, Incorporated, Boston, Massachusetts,
A STUDY OF TECHNIQUES FOR MONOSTATIC SYNTHETIC APERTURE RADAR, by Robert N. Maglathlin, William K. Talley, and Everett H. King, May 1964, Report No. RADC-TDR-64-42, Vol. 3, Contract No. AF 30(602)-3089, AD-422 420.

This report contains synthetic aperture analysis and computations, orbital analysis and computations, target resolution and angular accuracy, estimate of storage requirements, single target acceleration considerations for a flat Earth case, analysis of tracking parabolic filter, weighting functions for side-lobe reduction, derivation of the error in the measured eccentricity, the time rate of change of the difference in slant range, determination of the target dwell time, tracking accuracy requirements, effects of systems instabilities, the effects of angle and amplitude modulation on the coherent signal spectrum, and effects of variations in target aspect.

47. Ewart, D. G.,
THE EFFECT OF ATMOSPHERIC DRAG ON THE ORBIT OF A SPHERICAL EARTH SATELLITE, British Interplanetary Society Journal, Vol. 18, pp. 269-272, January-February 1962, A62-5319.

This article contains the derivation of solutions of the equations of motion for a spherical satellite in orbit within the Earth's atmosphere, by the method of variation of elements. Solutions are obtained for (1) the case of a spherical nonrotating Earth, and (2) the case where the atmospheric density decreases exponentially with altitude, the scale height being constant. Expressions for the changes in the orbital elements per satellite revolution are derived.

48. Fogarty, Laurence E. and Howe, R. M.,
AXIS SYSTEMS FOR ANALOG AND DIGITAL COMPUTATION OF SPACE AND REENTRY TRAJECTORIES, in Association Internationale Pour le Calcul Analogique, Colloque International des Techniques de Calcul Analogique et Numerique en Aeronautique, Proceedings, Liege, Belgium, 9-12 September 1963 (A65-19381 09-11), Brussels, Presses Académiques Européennes, 1964, pp. 464-473, A65-19428.

This presents an investigation of methods of real-time and fast-time computation of Earth orbits and re-entry trajectories, for both analog and digital computers. It is stated that integrator drift and multiplier errors in the case of analog computers preclude the use of direct computation in inertial frames or geocentric coordinate systems. Such coordinate systems can also lead to serious digital-computer problems due to truncation and roundoff errors. Introduction of a vehicle-centered rotating coordinate system with variables referred to a nominal orbit permits greatly improved computer scaling which, in turn, very substantially improves the absolute computational errors. In addition, the use of angular momentum and energy constraints is shown to reduce greatly the effect of integrator drift on the in-plane motion. Analog solutions to orbital and re-entry problems have been obtained in both real-time, fast-time, and high-speed repetitive operation using the above coordinate system. These results are presented along with an analog solution of the optimum continuous-thrust program for orbital transfer using the gradient method. Results of digital solution of this same orbital-transfer optimization problem are described. Use of the analog computer for continuous on-line smoothing of tracking data is presented.

49. Gdalevich, G. L.; Gringauz, K. I.; Rudakov, V. A.; and Rytov, S. M.;
THE EFFECTS OF IONOSPHERE ON THE DETERMINATION OF POSITION OF SPACE PROBES (K VOPROSU O VLIIANII IONOSFERY NA OPREDELENIE POLOZHENIIA KOSMICHESKIKH RAKET), Radiotekhnika i Elektronika, Vol. 8, pp. 942-949, June 1963, A63-19167 (In Russian).

This article is a discussion of the possibility of calculating the errors introduced by the ionosphere during the determination of coordinates and velocity of space-probe rockets by means of radio measurements. Expressions are given for these errors relative to the ionospheric parameters, and the possibility is considered of approximating the real altitude distribution of electron concentrations necessary for the calculation of the errors.

50. Gedeon, Geza S.,
LAMBERTIAN MECHANICS, in 12th International Astronautical Congress, Proceedings, Vol. 1, Washington, D. C., 1-7 October 1961, New York and London, England, Academic Press, Incorporated, 1963, pp. 172-190, A63-21249.

This is a presentation of orbital equations based on general initial conditions. These equations are not dependent on the orbital eccentricity and contain no reference to the line of apsides, thus they can be regarded as an extension of the work of Lambert, whose original equations are also rewritten in terms of a single power series valid for the full range of conic sections. The solution to the inverse of this power series equation is approximated by a polynomial devised by Hastings. Such a "Lambertian Mechanics" is as suitable for selecting interception trajectories (satellite, Moon, or planet) as "Keplerian Mechanics" is for determining the orbits of heavenly bodies.

51. Gedeon, Geza S.,
A RAPID METHOD FOR SELECTING INTERCEPTION TRAJECTORIES. Appendix A - THE EQUATION OF AN ORBIT WITH ARBITRARY INITIAL CONDITIONS. Appendix B - THE ORBITING TIME, Journal of Astronautical Sciences, Vol. 9, pp. 1-9, Spring 1962, A62-7398.

This article contains the derivation of orbital equations which are based on the angles measured from arbitrary initial positions, rather than those measured from the perifocus. The derived equations are presented in the form of tables, in which the terminal conditions (position vector, velocity vector, orbital times) of the interceptor are defined by the equality between the initial and terminal radii. Initial conditions are obtained by reversing the direction of motion; and the selection of interception trajectories is accomplished by listing the terminal conditions against the initial conditions. Nomograms for the solution of three-dimensional interception problems are given, and the use of the tables is illustrated by an example.

52. Geisler, Pamela A. and McVittie, G. C.,
ORBITAL PERIODS IN THE SCHWARZSCHILD SPACE-TIME, Astronomical Journal, Vol. 70, pp. 14-18, February 1965, A65-20618.

This article presents a general examination of the problem of relativistic orbital periods for the spherically symmetric field. These periods are compared with those obtained by classical methods. Only the Schwarzschild metric in standard form is used since the results for any other form may be obtained by coordinate transformations. The sidereal t-time period T_s of a relativistic orbit is compared with the period T_0 of a Newtonian orbit having (1) the same perihelion and aphelion distances, and (2) the same perihelion distance and the same velocity at perihelion. It is found that different methods of comparing relativistic and classical orbits lead to different values of the relative difference of $(T_o - T_s)T_o^{-1}$, and that therefore an experimental value of this difference would indicate which method of comparison should be adopted.

53. Gérardin, L.,
TRAJECTORY OF SPACE MISSILES, MEASURING RADARS OR INTERFEROMETERS (TRAJECTOGRAPHIE DES ENGINS SPATIAUX, RADARS DE MESURE OU INTERFEROMETRES), Navigation, Paris, France, Vol. 11, pp. 307-315, July 1963, A63-23072 (In French).

This article is a classification of methods for determining the trajectories of space missiles and satellites. Descriptions are given of various multistatic systems and of the monostatic localization system using radar. A comparison of these methods is made. Under consideration are the errors due to atmospheric disturbances that affect measurements, particularly, velocity measurements (which are more important than position measurements).

54. Gersten, Robert H. and Schwarzbein, Z. E.,
SELF-CONTAINED ORBIT DETERMINATION TECHNIQUES, American Institute of Aeronautics and Astronautics, Astrodynamics Conference, New Haven, Connecticut, Paper 63-431, 11 pp., 19-21 August 1963, A63-21739.

This article is an investigation of self-contained orbit determination techniques, any of which can be applied by space vehicles on geocentric, selenocentric, heliocentric, or planetocentric orbits. Observations of landmarks of the principal body, or stellar observations, are used to determine the orientation of the orbit plane in inertial space. Once the orientation is known, three more measurements are utilized to uniquely determine the two-body orbit. Orbit determination from the following combinations are considered: (1) three measurements of either the altitude, radial velocity, or time rate of change of true anomaly and the associated times; and (2) two measurements of any one of the above quantities, the first of which is taken simultaneously with the measurement of one of the other quantities.

55. Geyling, F. T.,
FUNDAMENTAL SATELLITE PERTURBATIONS, ARS Journal, Vol. 30, pp. 1009-1012, November 1960, A61-1301.

This article is a discussion, from an elementary point of view, of some basic satellite perturbations. The treatment serves to generate independent checks of formal results from more elaborate analyses and to establish a direct relation of these results to physical principles. The physical phenomena covered are: the distortion of an orbit within its own plane resulting from extraterrestrial gravitation; apsidal precession and buildup of eccentricity resulting from radiation pressure; apsidal precession and changes in epoch resulting from the equatorial bulge; and nodal precessions resulting from oblateness, extraterrestrial gravitation, and radiation pressure. The geometric relations between the orbit and the source of perturbation are specialized for maximum simplicity in each case. The quantitative results are precisely correct in all but one example, where a very good approximation of the true rate of precession is obtained. They may be extended to more general situations.

56. Geyling, F. T.,
DRAG DISPLACEMENTS AND DECAY OF NEAR-CIRCULAR SATELLITE ORBITS, AIAA Journal, Vol. 2, pp. 1174-1178, July 1964, A64-20405, (International Astronautical Federation Congress, Stockholm, Sweden, 1960).

This article contains a drag analysis performed for near-circular satellite orbits, as used in relay and re-entry missions. The work is formulated in terms of moving coordinates that have been previously applied to perturbation studies involving luni-solar gravitation and radiation pressure. The equations of motion for the satellite are written in terms of displacement components relative to an unperturbed Keplerian or "nominal" orbit. These components form an orthogonal triad, whose origin always lies at the nominal satellite position of the elliptic path. The rationale of working from some reference orbit is common to all established techniques of celestial mechanics. It is noted that, although the formulation presented uses the most primitive form of reference trajectory, the calculations remain simple enough to permit an allowance for moderate eccentricity of the nominal orbit and variability of atmospheric conditions. Predictions of orbit altitude and inclination during "spiral decay" are also possible. Perturbations in satellite coordinates, as provided, are stated to have obvious applications in guidance work.

57. Gontkovskvia, V. T. and Chebotarev, G. A., LUNAR AND SOLAR PERTURBATIONS OF LUNIK III, (Astronomicheskii Zhurnal, Vol. 38, pp. 954-960, September-October 1961), Soviet Astronomy, Vol. 5, pp. 728-732, March-April 1962, A62-5324 (Translation).

This article is a determination, by numerical integration, of the effect of lunar and solar perturbations upon the motion of Lunik III. The results are summarized and presented in tabular form.

58. Gooding, R. H., ANALYSIS OF OVERLAPPING SATELLITE DATA FROM TWO OR MORE STATIONS (WITH PARTICULAR REFERENCE TO KINETHEODOLITE OBSERVATIONS OF SPUTNIK II), Great Britain, RAE, TN G. W. 538, 26 pp., March 1960, A61-1300.

This article contains a description of a technique for combining angular observations from two or more kinetheodolite stations and comparison with the standard single-station technique. The new technique is used to obtain values of two orbital elements, those which fix the spatial position of the orbital plane, for each of the five transits of Sputnik II for which overlapping data were obtained.

59. Greene, Robert H., A METHOD OF COMPUTING SATELLITE POSITION IN LOW INCLINATION LOW ECCENTRICITY ORBITS AROUND AN OBLATE EARTH, American Institute of Aeronautics and Astronautics, Astrodynamics Conference, New Haven, Connecticut, Paper 63-395, 6 pp., 19-21 August 1963, A63-21712.

This article is a presentation of a method for computing the position of a satellite, using the orbital elements employed by Herrick for low-inclination, low-eccentricity orbits around an oblate Earth. The method involves an approximating potential function which leads to a resulting differential equation of motion in the orbital plane, the solution of which is obtained by a polynomial approximation to a series solution. The results of the method developed, as programmed for the IBM 7090 computer, were compared with the results of a computer program based on the method of Bakalyar for computing satellite position. The two methods agree to within 0.03 statute miles for several trial orbits.

60. Gunckel, Thomas L., II,
ORBIT DETERMINATION USING KALMAN'S METHOD, Navigation, Vol. 10, pp. 273-291, Autumn 1963, A64-10458, (Institute of Navigation, Western Regional Meeting, Anaheim, California, 16 April, 1963).

This article is an introduction of the application of optimal filtering techniques to the problem of satellite orbit determination. These techniques are based on the work of R. E. Kalman in the field of optimum estimation in linear sampled systems. The equations necessary to implement an on-board orbit determination system are presented and discussed. Simulation results are also presented to illustrate the validity of the approach and the value of the results for error analysis.

61. Hall, F. F., Jr., Stanley, G. V., and Dixon, T. P.,
RESEARCH ON THE DETECTION OF INFRARED EMISSION FROM SATELLITE VEHICLES, ITT Federal Laboratories, Science, Rep. 1 (AFCRL 215), 150 pp., December 1960, A62-984.

This article contains a description of an infrared radiometer capable of measuring radiation in the 1μ to 5μ regions, and presentation of techniques for predicting satellite orbits and optimizing search scan procedures. Cooled lead sulfide and indium antimonide detectors of f/1.0 and f/1.2 aperture, respectively, allow effective radiation measurement by coupling with background suppressing space filter-type chopper disks. A memory oscilloscope correlates low level signals by their ordered appearance in repeated line scans. Irradiance measurements from orbiting satellites are presented along with background sky conditions in daytime, nighttime, and in twilight.

62. Hall, N. S., Gawlowicz, H. G, and Wallman, E. J.,
THE CHOICE OF UNPERTURBED ORBIT IN THE USE OF ENCKE'S METHOD FOR THE EFFECTS OF OBLATENESS AND DRAG, ARS, Semi-Annual Meeting, Los Angeles, California, Preprint 1232-60, 13 pp., 9-12 May 1960, A61-3746.

This article contains an application of Encke's method to the orbits of near Earth satellites in the presence of oblateness and drag, using two choices of unperturbed orbit. The first is the elliptical orbit corresponding to a sperical Earth for the given initial conditions; the second is the approximate orbit about an oblate Earth. Since the analytical theories for both choices contain dependence upon initial conditions, rectification is straightforward. The results of six different calculations are presented: numerical integration of the differential calculations of satellite motion (Runge-Kutta-Gill); Encke's method using an elliptical base orbit, first-order Encke's series, and then alternately neglecting and including the derivative of the drag perturbation; Encke's method using an oblate base orbit, first-order Encke's series, and first neglecting and then including the derivative of the drag perturbation; and Encke's method using an oblate base orbit, a modified first-order Encke's series, and neglecting the derivative of the drag perturbation.

63. Herrick, Samuel,
POSITIONS, VELOCITIES, EPHEMERIDES REFERRED TO THE DYNAMICAL CENTER, California, University, UCLA, Astrodynamical Rep. 7 (AFOSR TN 60-773), 75 pp., July 1960, A61-3743.

This is a discussion and analysis of the problems of obtaining position and velocity for a given time from a set of orbital elements. Singularities in the problem occur when the eccentricity is zero or unity; it is in the treatment of these cases that the analysis differs from traditional works. A solution to Kepler's equation on the Comrie pattern is presented. A review of the formulation of the equations for the nearly circular ellipse is given, and the use of the unit vectors U_o and V_o is introduced. Kepler's equation is introduced in such a form that it is not necessary to solve for the eccentricity or to divide by the eccentricity at any point, so that the nearly-circular case formulas can be used down to and including the circular case without interruption or singularity. A series is given for nearly rectilinear or nearly parabolic orbits, which may also be used in differential correction schemes and perturbations by variation of parameters. Universal formulas which are applicable to all the conic sections, including the singular cases, are presented.

64. Holloway, Leith,
ALIGNMENT CHART FOR SATELLITE ORBIT CALCULATIONS, Journal of Astronautical Sciences, Vol. 8, pp. 60 and 61, Summer 1961, A61-8730.

This article is a presentation of an alignment chart for the evaluation of the first-approximation formulas used in the calculation of theoretical values for the rates of motion of the nodes and perigee of a satellite orbit. These calculations are helpful in tracking a satellite during the first few days following its launching, when accurate machine-computed ephemerides are not yet available. Convenient transformations of the first approximation formulas are included.

65. Hudson, J. L. and Kehayas, E. C.,
AN OPERATIONAL RESEARCH STUDY OF THE DETERMINATION AND PREDICTION OF SATELLITE ORBITS, Canadian Operational Research Society, Journal, Vol. 2, pp. 13-25, June 1964, A64-19153, (Canadian Operational Research Society and Operations Research Society of America, Joint Conference, Montreal, Canada, 27-29 May 1964).

This article is a discussion of the acquisition and tracking of modern space vehicles by sensors in a ground-based network. Measurements made by these sensors are used to derive estimates of the orbits of the space vehicles and of their positions and velocities at any time. The degree of accuracy required in this process is stated to be greater as the space operations become more complex. However, this accuracy is a function of many factors associated with the sensor network. These factors include the type of measurements made by each sensor, the accuracy of the individual measurements, the frequency of measurement, and the geographic distribution of the sensors. A description is provided of a study designed to establish the relationship between these factors and the accuracy of orbital determination. Also provided are a description of the method of analysis and some typical results of the study.

66. Institute of Geodesy; Photogrammetry and Cartography; Ohio State University, Research Foundation, Columbus, Ohio,
ON THE ACCURACY OF SPHERICAL HARMONICS AND ORBITAL PREDICTIONS, by Helmut Moritz, June 64, Report No. 6, AFCRL-64-566, VI, Contract No. AF 19(628)-1628, AD-605 659.

This report derives the needed formulas for gravity potential, and handles the standard error of the obtained coefficients of spherical harmonics. Satellite orbits are influenced by the irregularities of the Earth's gravity field, which are usually expressed in terms of a development in spherical harmonics. Thus, we must know the gravity field, i. e., the coefficients of this development, for precise prediction of satellite orbits. These spherical harmonics coefficients can be determined either from the analysis of known satellite orbits or from gravity measurements at the surface of the earth. The accuracy of the orbital elements of the satellites, computed from gravity anomalies, the determination of the gravimetric constant G M, and the position of the tracking stations are handled in this report. If the gaps of the gravity anomalies in the oceans at the continents can be filled, the gravimetric method can help the satellite geodesist in many respects.

67. Jacchia, Luigi G.,
THE DETERMINATION OF ATMOSPHERIC DRAG ON ARTIFICIAL SATELLITES, in Dynamics of Satellites, Proceedings of the IUTAM Symposium, Paris, France, 28-30 May 1962, New York, Academic Press, Incorporated, 1963, pp. 136-142, A64-12666.

This contains a description of a practical method for determining the atmospheric drag on artificial satellites, involving the analysis of the mean anomaly over long time-intervals. Analytical time functions are fitted to all the final elements; no systematic residuals are permitted, except in the mean anomaly, where residuals ΔM up to 10^{-3} revolutions are tolerated. The individual values of ΔM are plotted and a smooth curve is drawn through the points. The period variation is determined from the reference equation for the mean anomaly and from the second time-derivative of the ΔM curve, with allowance for the acceleration of the perigee.

68. Kalil, Ford,
MINIMUM ALTITUDE VARIATION ORBITS ABOUT AN OBLATE PLANET, AIAA Journal, Vol. 1, pp. 1655-1657, July 1963, A63-19436.

This article contains a derivation of a method and corresponding analytical expressions for determining the orbital parameters for an orbit that closely follows the contour of the Earth. During one-quarter of each revolution there is a minimum altitude variation throughout an operational time of several days. The first-order theory of Struble is used. A cursory study indicates that such a class of orbits is quite feasible.

69. Kaula, W. M.,
ANALYSIS OF GRAVITATIONAL AND GEOMETRIC ASPECTS OF GEODETIC UTILIZATION OF SATELLITES, U. S. NASA TN D-572, 40 pp., March 1961, A61-5846.

This is a derivation of expressions for the first-order effects of any period of a given term of the gravitational potential on the orbital elements, and for the second-order effects arising from the interaction of the term with the oblateness. A general geometric and statistical treatment of all types of observations is developed, with the purposes of obtaining rigorous evaluations of orbital and observational schemes, and optimum solutions for geodetic positions, gravitational harmonic coefficients, and orbital elements.

70. Kevorkian, J. and Murphy, J. F.,
COMMENT ON "SATELLITE MOTIONS ABOUT AN OBLATE PLANET," AIAA Journal, Vol. 1, pp. 1710 and 1711, July 1963, A63-19471.

This articles states that a mixed secular term contained in the Anthony-Fosdick solution of the problem of satellite motion about an oblate planet can be eliminated by expressing the solution in a frame that rotates at an appropriate uniform rate about the polar axis. This technique is used for satellite motions in the restricted three-body problem.

71. King-Hele, D. G.,
DISCOVERIES FROM SATELLITE ORBITS, International Council Aeronautical Sciences, 2nd International Congress, Zurich, Switzerland, Preprint, 26 pp., 12-16 September 1960, A61-563.

This article is a discussion of findings made on the basis of the changes in satellite orbits, which occur as a result of the effects of air drag and any peculiarities in gravity. New knowledge in the following subjects is presented: the shape of the earth, which is less flattened than was previously believed and is slightly pear-shaped; the average density of the upper atmosphere, which at heights of 200 to 700 kilometers is much greater than was previously supposed; and the variations in upper-air density, which prove to be strongly under solar control.

72. King-Hele, D. G.,
REVIEW OF EARTH-SATELLITE ORBITAL STUDIES AT R.A.E., 1957-61, AND THEIR APPLICATION TO RUSSIAN AND AMERICAN SATELLITES, Great Britain, RAE, Rep. G. W. 25, 390 pp., July 1961, A62-5330.

This article presents a summary of studies on prediction methods, the determination of orbits from observations, orbital theory, and the geophysical information derived from measuring orbital perturbations. Some 18 reports and articles on these subjects by different authors are reprinted in the appendices.

73. King-Hele, D. G.,
THE CONTRAGTION OF SATELLITE ORBITS UNDER THE ACTION OF AIR DRAG, ALLOWING FOR THE VARIATION OF SCALE HEIGHT WITH ALTITUDE, in Dynamics of Satellites, Proceedings of the IUTAM Symposium, Paris, France, 28-30 May 1962, New York, Academic Press, Incorporated, 1963, pp. 211-218, A64-12674.

This is a presentation of equations which specify the contraction of satellite orbits under the influence of air drag in an atmosphere with a constant "density scale height" H. It is shown how these equations are to be modified when H varies with height. Some examples are given of values of H determined by means of these equations from the observed changes in satellite orbits.

74. King-Hele, D. G., Cook, G. E,, and Walker, D. M. C.,
THE CONTRACTION OF SATELLITE ORBITS UNDER THE INFLUENCE OF AIR DRAG. II - WITH OBLATE ATMOSPHERE, Great Britain, RAE, TN G. W. 565, 92 pp., December 1960, A61-5858.

This article is an extension of a previously published analysis to the case of an atmosphere in which the surfaces of constant density are spheroids of arbitrarily small ellipticity. Expressions for the variation of perigee distance and orbital period with eccentricity, and for the relation of eccentricity to time, are derived. Expressions for lifetime and air density at perigee in terms of the rate of change of period are also obtained. Circular orbits are treated separately. Results are also presented graphically, and examples of applications of the theory are given.

75. King-Hele, D. G.,
THE CONTRACTION OF SATELLITE ORBITS UNDER THE INFLUENCE OF AIR DRAG. III - HIGH-ECCENTRICITY ORBITS ($0.2 \leq e < 1$), Great Britain, RAE, In Space 1, 31 pp., January 1962, A62-6341.

This is a derivation of equations which show how perigee distance and orbital period vary with eccentricity during the satellite's life, and how eccentricity is related to time. Formulas are obtained for the lifetime and the air density at perigee, in terms of the rate of change of period. The results are presented graphically, and their implications and limitations are discussed.

76. King-Hele, D. G.,
THE CONTRACTION OF SATELLITE ORBITS UNDER THE INFLUENCE OF AIR DRAG. III - HIGH-ECCENTRICITY ORBITS ($0.2 \leq e < 1$), Royal Society, London, England, Proceedings, Series A, Vol. 267, pp. 541-557, 5 June 1962, A62-7393.

This article contains a derivation of equations which show how perigee distance and orbital period vary with eccentricity during the satellite's life, and how eccentricity is related to time. Formulas are obtained for the lifetime and the air density at perigee, in terms of the rate of change of period. The results are also presented graphically and their implications and limitations are discussed.

77. Kooy, J. M. J.,
ON THE METHOD OF VARIATION OR ORBIT ELEMENTS IN CASE OF FINITE SPEED OF GRAVITATION, in 12th International Astronautical Congress, Proceedings, Vol. 2, Washington, D. C., 1-7 October 1961, New York and London, England Academic Press, Incorporated, 1963, pp. 963-998, A63-21300.

This article contains a description of a method for finding the elliptic orbital elements as functions of time for problems involving two planets disturbing one another. A finite speed of gravitation and relativistic interdependence are assumed. The attraction of the Earth on an artificial satellite is analyzed for a near-Earth satellite, taking into account a finite speed of propagation of the gravitational waves, and assuming the Earth to be a three-axial ellipsoid rotating about its smallest axis.

78. Kork, Jyri,
SATELLITE LIFETIMES IN ELLIPTIC ORBITS, 30th IAS Annual Meeting, New York, New York, Paper 62-5, 35 pp., 22-24 January 1962, A62-3079.

This article contains a derivation of analytical decay rates of orbital elements for instantaneous conditions, and determination of the total lifetimes by numerical integrations of the decay rates on an IBM 709 computer. The ARDC 1959 atmospheric density model is used as the basis for calculations. The orbital decay rates are derived from Lagrange planetary equations, using series expansions up to the fourth power of the eccentricity. Applying the Krylov-Bogoliuboff averaging process, the average instantaneous decay rates are found by integrating the series expansions over one full orbital revolution. Assuming exponential air density distributions for this period, the integrals of decay rates are obtained in the form of modified imaginary Bessel functions up to the fourth order, which are reduced to series expansions of modified Bessel functions of orders zero and one. A generalized lifetime plot for the ballistic coefficient of unity ($C_D A/2M = 1\ ft^2/slug$) and the apogee and perigee decay rates for the same ballistic coefficient are given for initial perigee altitudes from 80 to 400 miles, and for initial eccentricities from 0 to 0.4.

79. Koskela, P. E.,
PRELIMINARY ORBIT DETERMINATION FROM ANGULAR OBSERVATIONS, IAS, National Summer Meeting, Los Angeles, California, Paper 62-174, 8 pp., 19-22 June 1962, A62-8360.

This article contains a development of a preliminary orbit determination method using angular observations spaced over a large arc. The Gaussian orbit determination method is successfully adapted to the problem. The customary series expansions used to obtain initial position vectors are avoided by first fitting a circular orbit to two observations. A third observation is used to resolve the possible ambiguity in the direction of motion when the observations are not close together in time and position. The semimajor axis of this circular orbit is taken as an initial estimate to the geocentric radial distances on the three observation dates. Gauss's ratio of sector-to-triangle theory then forms the basis of an iterative procedure for converging upon the actual geocentric position vectors. The traditional series solution of the sector-to-triangle relationships is avoided. The geocentric velocity vector on the central date follows from the three geocentric position vectors and the time intervals.

80. Kovalevsky, J.,
THE STUDY OF TRAJECTORIES OF ARTIFICIAL SATELLITES (L'ETUDE DES TRAJECTOIRES DES SATELLITES ARTIFICIELS), Revue Francaise d'Astronautique, pp. 211-215, September-October 1963, A64-11700 (In French).

This is a discussion of the two different stages of the study of the motion of space rockets, in order to find the parameters which characterize their trajectory, and to make a forecast of their future position. Considered are the optical methods of observation (visual and photographic), theoretical studies, and geodesy by means of satellites. The necessity is pointed out for enhancing the French facilities and resources, in order to be able to track and forecast the passage of French satellites scheduled for launching.

81. Krause, Helmut G. L.,
ASTRORELATIVITY, in 12th International Astronautical Congress, Proceedings, Vol. 1, Washington, D. C., 1-7 October 1961, New York and London, England, Academic Press, Incorporated, 1963, pp. 131-160, A63-21247.

This article is an extension of the special theory of relativity to include generalized relativistic conservation laws of momentum and total energy for bodies whose proper or rest mass is variable with time - i. e., rockets. Relativistic dynamics is applied to rocket propulsion. Both motion and mass consumption of a rocket under a constant proper acceleration and under a constant mass flow rate or constant thrust are investigated. Einstein's general theory of relativity (gravitational theory) is applied to the motion of an artificial satellite revolving in an arbitrary orbit around a rotating, nonhomogeneous, oblated spheroidal central body. This relativistic perturbation theory is an extension of the work of Einstein, deSitter, and of Lense and Thirring. A formula for the relative difference of the time rates of a satellite clock, compared against a standard Earth clock (time dilatation effect and red shift), is derived for arbitrary orbits.

82. Leach, Richard F.,
EVALUATING THE QUALITY OF PREDICTION OF A POSITION-PREDICTING OR TRACKING SYSTEM, in 12th International Astronautical Congress, Proceedings, Vol. 1, Washington, D. C., 1-7 October 1961, New York and London, England, Academic Press, Incorporated, 1963, pp. 161-171, A63-21248.

This article is a presentation of a method for evaluating the error in prediction for a satellite-borne system that uses an occultation instrument. The effect of the addition of a radar altimeter is also studied. It is shown that the best prediction for deterministic trajectories is equivalent to the maximum-likelihood evaluation of the constants of integration. It is also shown that the quality of prediction is based on the accuracy of the evaluation of the constants, which leads to a triaxial prediction ellipsoid.

83. Lecar, Myron,
A METHOD OF ESTIMATING RESIDUALS IN ORBITAL THEORY, U. S. NASA TN D-493, 10 pp., January 1961, A61-2026.

This is a presentation of a method for estimating the magnitude of the residuals (differences between calculated and observed positions) to be expected from an approximate theory presumed to have one missing or incorrect term. Such estimation cannot be made if a least-squares procedure is used to fit theory to observation, since this procedure tends to obscure the significance of theoretical parameters, so that the physical sources of residuals cease to be apparent.

84. Lenzi, Ernesto,
TIME LAW IN SATELLITE MOTION (LA LEGGE DEI TEMPI NEI MOTI DEI SATELLITI), Rivista Aeronautica, Vol. 39, pp. 255-263, February 1963, A63-18874 (In Italian).

This article contains a derivation of the time law for the various types of satellite trajectories. Several examples are calculated, and a table of summarized data for parabolic and hyperbolic orbits is included.

85. Levin, E. and Lewis, D. H.,
VARIATION OF SATELLITE POSITION WITH UNCERTAINTIES IN THE MEAN ATMOSPHERIC DENSITY, IAS-ARS, Joint National Meeting, Los Angeles, California, Paper 61-138-1832, 44 pp., 13-16 June 1961, A61-7794.

This is a study of the effects of the uncertainty in the mean atmospheric density at any given altitude on the altitude, in-track position, and cross-track position of satellites. Analytic relations between the in-plane position and the mean atmospheric density, and the number of revolutions since the last precise orbit determination are found. This analysis is valid for near-circular orbits of any inclination about a spherical Earth. An uncertainty in predicted period will occur due to the uncertainty in mean atmospheric density. This period uncertainty, coupled with the rotation of the Earth, gives rise to a lateral (cross-track) displacement of the locus of subsatellite points. The effects of this displacement on the azimuths and rise times required for satellite acquisition are considered. Only circular polar orbits about a spherical rotating Earth are considered. Good agreement is found between analytic predictions and machine-integrated orbits.

86. Lidov, M. L.,
EVOLUTION OF THE ORBITS OF ARTIFICIAL SATELLITES OF PLANETS AS AFFECTED BY GRAVITATIONAL PERTURBATION FROM EXTERNAL BODIES, (Iskusstvennye Sputniki Zemli, No. 8, pp. 5-45, 1961), AIAA Journal, Russian Supplement, Vol. 1, pp. 1985-2002, August 1963, A63-20527 (Translation).

This article is a derivation of simple expressions useful for studying the evolution of a broad range of satellite orbits as affected by gravitational forces of other celestial bodies, such as the Sun and the Moon. These expressions reveal the basic qualitative regularities of motion, and provide, with a certain degree of accuracy, a way of obtaining quantitative estimates of short-term and long-term changes. The basic assumption made is that there is a small enough ratio between the height of the apocenter of the satellite and the distance from the perturbing body to the central body. The second assumption made is that any variation in orbital elements for one revolution of the satellite is small. Approximate formulas are derived for the variation in orbital elements for one revolution of the satellite, for several revolutions, and for the period of revolution of the perturbing body. The results are compared with those obtained by the numerical integration of the differential equations, and it is concluded that although the error in the approximate method is appreciable (of the order of several percent), the method is sufficiently accurate for research purposes and for the preliminary computation of a class of satellite orbits broad enough to be useful in actual practice.

87. Lidov, M. L.,
ON THE APPROXIMATED ANALYSIS OF THE ORBIT EVOLUTION OF ARTIFICIAL SATELLITES, in Dynamics of Satellites, Proceedings of the IUTAM Symposium, Paris, France, 28-30 May 1962, New York, Academic Press, Incorporated, 1963, pp. 168-179, A64-12669 (Translation).

This is a discussion of the approximated calculation of the evolution of individual orbits of artificial satellites at a considerable time interval. Exact estimates of the lifetime of a type of "Moon" were obtained by numerical integration of the set of differential equations of the combined motion of the Earth, Sun, and the satellite, with the noncentricity of the Earth's gravitational field taken into account. This example illustrates the efficiency of the approximated formulas not only in a qualitative, but also in a quantitative aspect.

88. Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts,
REDUCTION OF COMPUTATIONAL AND DATA TRANSMISSION REQUIREMENTS FOR TRAJECTORY ESTIMATION USING MULTIPLE SITES, by Fred C. Schweppe, August 1963, Report No. ESD-TDR-63-102, Contract No. AF 19(628)-500, AD-416 742.

Space vehicles in free fall are often tracked from tracking sites located at different points on the Earth. Two basic techniques for estimating the trajectory from the combined tracking data are discussed. These techniques are related to the maximum likelihood procedure but allow faster computation and do not require the transmission of all of the data to a common data reduction center.

89. Lockheed Aircraft Corporation, Sunnyvale, California, Meteorological Research Committee Air Ministry, London, England,
AICBM-INSATRAC SYSTEM STUDY, VOL. II, APPENDICES, January 1960, Report No. ARDC-TR-59-8, Contract No. AF 18(600)-1847, AD-406 991.

In this volume (Volume II), six appendices are presented of detailed analyses and technical studies which support some of the findings presented in the second semiannual report on the AICBM-INSATRAC System Study, Volume I. Appendix A contains a generalization of conventional queueing theory which applies to some system saturation problems. Appendix B is

a procedure for triangulation from two stations in three dimensions, and an error analysis of the process. Appendix C presents several triangulation procedures for two or more stations in three dimensions. Appendix D presents calculations and graphs of several geometric functions associated with satellite systems. Appendix E is a continuation of the study presented in the first semiannual report on the topic of data-smoothing with digital systems. Appendix F presents the results of an intensive study of the feasibility of high-precision tracking of satellites.

90. Lockheed Missiles and Space Company, Sunnyvale, California, DATA PRESENTATION FOR POSITIONAL REPRESENTATION OF SPACE VEHICLES (PHASE III), by A. C. Block, L. A. Delateur, R. L. Nelson, and L. J. Stempson, January 1965, Report No. RADC-TDR-64-291, Contract No. AF 30(602)-3119, AD-459 462.

This is the final report of a three-phase effort to study information requirements for the positional representation of space vehicles and to develop associated display techniques. The phase III program described in the report includes (1) reconsideration of all major principles formulated in the earlier phases, (2) development of methods to illustrate how and why information items are selected and associated for display to the CINC Level commander, and (3) test, through analytical methods, of the effects of space vehicle types, numbers, and maneuvering capability on proposed formats.

91. Longden, G. B. and Law, R. B., ON S. P. ALTMAN'S PAPER "ORBITAL TRANSFER FOR SATELLITES," Planetary and Space Science, Vol. 12, pp. 17-20, January 1964, A64-15083.

This article presents an evaluation of Altman's definition of a planar orbit in terms of two velocity parameters, rather than the conic parameters, and of his use of this formulation to obtain the "differential accelerations" necessary for transfer between elliptical orbits. It is pointed out that Altman's formulas are incorrect due to a misinterpretation of the time rate of change of the "true anomaly" during the powered phase of transfer. The correct form of these differential accelerations is derived and the implications of such corrections are considered.

92. Lorell, Jack and Anderson, John,
PRECESSION RATES FOR AN ARTIFICIAL SATELLITE, in 13th International Astronautical Congress, Proceedings, Vol. I, Varna, Bulgaria, September 1962, Vienna, Austria, Springer-Verlag, 1964, pp. 451-461, A64-28465,

This article presents the development of a procedure for evaluating the long-period component and secular component of satellite motion. The motion of an orbiting satellite is considered to be composed of three elements: (1) A short-period component, the period of which is of the same order as that of the primary motion; (2) A long-period component consisting of all sinusoidal motions with periods in excess of that of the primary motion, in particular, of those influenced by periodic perturbing forces; and (3) A secular component which is not periodic. The proposed procedure is based on Lagrange's planetary equations. The perturbative function is averaged with respect to the mean anomaly, to provide the secular and long-period variations. Instead of the perturbative function, use can also be made of the perturbing force from the planetary equations. The method is applied to motions where the perturbing forces are: (1) an oblate gravity field, (2) a longitudinal bulge in a gravity field, (3) a third body, (4) constant radial acceleration, (5) constant tangential acceleration, and (6) relativistic accelerations.

93. Lowitt, Peter M. and Shinners, Stanley, M.,
INTEGRATED OPTIMAL SYNTHESIS FOR A RADAR TRACKER, in 7th National Convention on Military Electronics, Proceedings, Washington, D. C., 9-11 September 1963, (Conference sponsored by the Professional Technical Group on Military Electronics, Institute of Electrical and Electronics Engineers), New York, Institute of Electrical and Electronics Engineers, 1963, pp. 74-78, A64-22489.

This is a description of original contributions made in the area of satellite trackers. A technique known as IORST is presented. Using this technique, it is shown that a type -3 tracking configuration having a highly damped, minor rate, feedback loop in conjunction with acceleration feedback is an optimum configuration for the requirements of a typical modern satellite tracker from the viewpoint of load resonances, nonlinear friction, and opposing wind torques. In addition, analytic techniques utilizing signal flow graphs in conjunction with describing functions for the anticipated nonlinearities are used to analyze a proposed type -3, ninth-order, tracking system from the viewpoint of accuracy and stability.

94. Lubowe, Anthony G.,
HIGH ACCURACY ORBIT PREDICTION FROM NODE TO NODE, Astronautica Acta, Vol. 10, No. 3-4, pp. 252-261, 1964, A65-18102.

This article presents a conversion of the high accuracy orbit prediction method, developed earlier by the author et al, as part of the tracking and prediction program for the Telstar satellite, to the special case of node-to-node operation. Node-to-node prediction is shown to be suitable for the following uses: (1) tracking and prediction for a worldwide satellite communication system utilizing field computers with low storage capacities and low computation speed; and (2) long-range orbit prediction using multistep methods. Total storage requirements are reduced by 37 per cent and computation time on the IBM 7094 by 12 percent.

95. Lundbak, A.,
SOME SIMPLE FORMULAS FOR LATITUDE EFFECTS AND LIFETIMES OF SATELLITES, Planetary and Space Sciences, Vol. 2, pp. 212 and 213, August 1960, A61-548.

This article presents an analysis of the effect which manifests itself in the orbital period of a satellite because of the latitudinal shifting of the perigee. The American satellites Discoverer V and Discoverer VI (both 1959) offered good opportunities for such an analysis, especially after elimination of the normal decrease of the orbital period. Hereby, the latitude effect has turned out to mean deflections in the decrease of the orbital period about 20 per cent from the average. Some consequences as to air pressure and lifetimes of satellites are implied.

96. Marchal, Christian,
MOVEMENT OF ARTIFICIAL EARTH SATELLITES IN TERMS OF THE SOLUTION OF THE PROBLEM OF TWO FIXED CENTERS (MOUVEMENT DES SATELLITES ARTIFICIELS DE LA TERRE A PARTIR DES SOLUTIONS DU PROBLEME DES DEUX CENTRES FIXES), Académie des Sciences (Paris, France), Comptes Rendus, Vol. 258, No. 1, pp. 79-81, 6 January 1964, A64-21457.

This is a presentation of a method of defining satellite movement in terms of a point subjected to the Newtonian attraction of two fixed pinpoint masses. The disymmetries of terrestrial potential constitute by far the most important cause of perturbations for a near satellite. However, this potential can be resolved in terms of two fixed centers (in imaginary positions, because the Earth is flattened and not elongated) with an error 1000 times smaller than when it is resolved in terms of a single center. In application, a very exact result is obtained, because the perturbations, or differences between real forces and those due to the two imaginary centers, are very small, giving a position error of 30 meters.

97. Mass, Jonathan,
NOUVELLES POSSIBILITIES OFFERTES PAR LA MESURE DE L'AMPLITUDE DES SIGNAUX RADIOELECTRIQUES DES SATELLITES ARTIFICIELS, Académie des Sciences, Séances, Comptes Rendus, Vol. 253, No. 17, pp. 1832 and 1833, 1961, A62-982.

This is a discussion of the determination of the orientation of an artificial satellite by the study of its electromagnetic emission. It is shown that, in the case of satellites whose radiation is circularly polarized, it is possible to determine, from the Faraday effect, not only the orientation of the satellite, but also the amplitude of the signal, independently of this orientation.

98. Maxwell, James A. and Dorfman, Merlin,
THE ACCURACY OF SATELLITE ORBIT DETERMINATION, American Institute of Aeronautics and Astronautics, Summer meeting, Los Angeles, California, Paper 63-155, 23 pp., 17-20 June 1963, A63-18744.

This paper presents the development of general equations for evaluating the accuracy of a real-time or postflight satellite ephemeris, generated from ground tracking data. Sources of error considered are: (1) random observational errors, (2) data bias uncertainties, (3) tracking-station position uncertainties, (4) tracking-station clock uncertainties, (5) tracking-station local coordinate uncertainties, (6) systematic air-drag uncertainties, (7) random forces acting on the vehicle, and (8) gravitational uncertainties. Assuming the use of a weighted least-squares fit of orbital equations to a set of radar tracking data, results from a computational program based on the theory are presented. It is shown that under some circumstances, a significant reduction in ephemeric uncertainty due to random drag fluctuations can be achieved if care is used in selecting the weighting technique used in the weighted least-squares fit.

99. Mersman, W. A.,
THEORY OF THE SECULAR VARIATIONS IN THE ORBIT OF A SATELLITE OF AN OBLATE PLANET, U. S., NASA TR R-99, 78 pp., 1961, A61-5849.

This presents an application of a new set of canonical variables to analyze the theory of satellite orbits about an oblate planet. The Hamiltonian function is separated into two parts, one of which is neglected. The neglected part is periodic with mean value equal to zero, and it vanishes when the inclination is zero. Thus the solution obtained by neglecting this part of the Hamiltonian is exact for equatorial orbits; for inclined orbits, the secular motion of the node and perigee are obtained correctly to the second order of the oblateness parameter. For satellite orbits, the geometric equation of the trajectory is obtained in the classical form in terms of true and eccentric anomalies, with these being related to the physical angle (argument of latitude) by transformations involving elliptic functions. The kinematic equation obtained is a natural generalization of Kepler's equation. All the orbital elements are constants in this approximation; the perturbation equations for the elements are presented but not solved. An example based on the satellite 1958 β 2 (Vanguard I) is included. Secular motions are predicted accurately, and periodic motions within the limitations of the theory. Relativistic effects are shown to be negligible as far as the geometry of the orbit is concerned, while the secular drift of a satellite-borne clock is shown to be on the fringe of detectability.

100. Mitre Corporation, Bedford, Massachusetts,
A BRIEF SURVEY OF SATELLITE ORBIT COMPUTATION METHODS AND MAJOR PERTURBATIVE EFFECTS, by Robert H. Greene, March 1964, Report No. ESD-TDR-63-477, Contract No. AF 19(628)-2390, AD-434 348.

A brief descriptive survey of the various satellite orbit computation methods is presented in order to give the systems engineer an introduction to the various methods and problems which currently exist.

101. Muller, Paul,
ON THE ACCURACY LIMITS OF PHOTOGRAPHIC OBSERVATIONS OF ARTIFICIAL SATELLITES (SUR LES LIMITES DE LA PRECISION DES OBSERVATIONS PHOTOGRAPHIQUES DE SATELLITES ARTIFICIELS), Académie des Sciences (Paris, France), Comptes Rendux, Vol.257, No. 18, pp. 2613-2615, 28 October 1963, A64-10547 (In French).

This article presents a solution to the problem of defining a number of points on the trail left on a plate by a satellite, in relationship to the star background, provided that it is possible to give to each of the points the time corresponding to the satellite passage. The photographic equipment and procedure used in the experiment are described. The deviations found are as follows: (1) on a star: 0.9 second per coordinate; and (2) on the satellite: 2 seconds per coordinate. It is stated that this accuracy has not otherwise been achieved even with much more powerful devices.

102. Musen, Peter,
A MODIFIED HANSEN'S THEORY AS APPLIED TO THE MOTION OF ARTIFICIAL SATELLITES, U. S., NASA TN D-492, 39 pp., November 1960, A61-2798.

This is a presentation of a theory of oblateness perturbations of the orbits of artificial satellites based on Hansen's theory, with modification for adaptation to fast machine computation. The theory permits the easy inclusion of any gravitational terms, and is suitable for any deduction of geophysical and geodetic data from orbit observations on artificial satellites. The computations can be carried out to any desired order compatible with the accuracy of the geodetic parameters.

103. Musen, Peter; Bailie, A.; and Upton, E.;
DEVELOPMENT OF THE LUNAR AND SOLAR PERTURBATIONS IN THE MOTION OF AN ARTIFICIAL SATELLITE, U. S., NASA TN D-494, 44 pp., January 1961, A61-2800.

This presents an analysis of the problems relating to the influence of lunar and solar perturbations on the motion of artificial satellites by means of an extension of Cayley's development of the perturbative function in the lunar theory. The results are modified for incorporation into the Hansen-type theory used by the NASA Space Computating Center.

The theory is applied to the orbits of the Vanguard I and Explorer VI satellites, and the results of detailed computations for these satellites are given together with a physical description of the perturbations in terms of residance effects.

104. Musen, Peter,
ON LONG RANGE EFFECTS IN THE MOTION OF ARTIFICIAL SATELLITES, in Dynamics of Satellites; Proceedings of the IUTAM Symposium, Paris, France, 28-30 May 1962, New York, Academic Press, Incorporated, 1963, pp. 21-33, A64-12657.

This presents an application of the Halphen-Goriachev method to the investigation of long-range stability of artificial satellites. This permits the numerical integration of long range lunar effects over an interval of many years. Numerous examples are computed and plotted. The long range solar effects are treated by averaging the disturbing function over the orbit of the satellite. The effects in the motion of a 24-hour satellite caused by the ellipticity of the Earth's equator are treated using a resonance theory.

105. Musen, Peter,
ON THE LONG-PERIOD LUNISOLAR EFFECT IN THE MOTION OF THE ARTIFICIAL SATELLITE, Journal of Geophysical Research, Vol. 66, pp. 1659-1665, June 1961, A61-6801.

This article is a presentation of two systems of formulas for the determination of the long-period perturbations caused by the Sun and the Moon in the motion of an artificial satellite. The first method is based on the theory originally developed by Gauss, and can be used to determine the lunar effect on all satellites. The second method is based on the development of the disturbing function in terms of Legendre polynomials, and is more convenient for finding the lunar effect on close satellites and the solar effect on all satellites. The basic equations of both systems are arranged in a form permitting numerical integration.

106. Musen, Peter,
THE THEORY OF ARTIFICIAL SATELLITES IN TERMS OF THE ORBITAL TRUE LONGITUDE, Journal of Geophysical Research, Vol. 66, pp. 403-409, February 1961, A61-4757.

This article presents a further development of the author's theory of the artificial satellite. The limitations of the previous theory, which used the eccentric anomaly as the independent variable, are avoided by a new derivation in terms of the orbital true longitude. Faster convergence is thus obtained for large eccentricities, as well as a smaller number of terms in the series representing the perturbations. Each approximation of the radius vector, and of the parameters determining the position of the orbit plane, is obtained not in the form of a truncated infinite series, but in the form of trigonometric polynomials in two arguments (the mean true anomaly and the mean argument of the latitude). Mathematically simpler, more compact, and of wider validity than the previous theory, the new derivation is also more convenient from the standpoint of numerical computation. Programming is simpler, requiring less memory space. Greater flexibility is thus obtained, and room provided for future refinements as information about the external gravitational field of the Earth becomes more accurate.

107. Naumann, Robert J.,
OBSERVED TORQUE-PRODUCING FORCES ACTING ON SATELLITES, in Dynamics of Satellites; Proceedings of the IUTAM Symposium, Paris, France, 28-30 May 1962, New York, Academic Press, Incorporated, 1963, pp. 237-256, A64-12677.

This presents a discussion of some of the experimental satellite orientation data, with the view of explaining the nature and origin of the torques responsible for the observed motion about the center of mass. To solve the orientation equations, it is necessary to determine the nature of the torque-producing forces. This is done by observing the change in orientation of several Explorer satellites where the drag force is sufficiently small so the orbital dependence on orientation is negligible. It was found that permanent magnetic moments in the satellites were the dominant effect responsible for the observed changes in orientation. Gravitational torques are also significant. The changes in orientation of the satellites considered were explained extremely well by these two effects; hence it is concluded that other effects are not significant for similar satellites. Various approximations are used in this study which greatly reduce the effort required to integrate the orientation equations and do not require the simultaneous solution of the orbital equations. The findings, however, are applicable to the simultaneous solution of both the orbital and orientation sets of equations.

108. Naval Research Laboratory, Washington, D. C.,
FIRST ORDER OBLATENESS PERTURBATIONS AND THE U. S. NAVAL SPACE SURVEILLANCE SYSTEM, by Thomas B. Murtagh, November 1964, Report No. NRL-6169, Master's Thesis, AD-609 566.

An error analysis is presented involving a comparison of position errors in the orbital path of an artificial Earth satellite produced either by the inclusion or omission of first order oblateness effects on all of the orbital elements or by the introduction of theoretical errors into the system with which the measurements are made. The reasons for making the above comparison are twofold. First, if the improved model of the Earth's gravitational field produces an increased accuracy in the orbital elements commensurate with the accuracy of the measuring system, then this more accurate model should be used in the derivation of any epoch set of orbital elements from raw data as well as in any scheme for predicting satellite position as a function of time from epoch. Secondly, if the improved model accuracy is indeed not comparable to the measuring system accuracy, then the inclusion of these first order effects is not necessary and their omission will reduce expenditures for the use of the high speed digital computer necessary for orbital element computation and updating.

109. Naval Research Laboratory, Washington, D. C.,
THE COMPUTATION OF OPTIMUM ORBITAL ELEMENTS DERIVED FROM A SINGLE COINCIDENT OBSERVATION BY TWO RECEIVING STATIONS OF THE NAVAL SPACE SURVEILLANCE SYSTEM, by Howard Gerald Devezin, Jr., October 1964, Report No. NRL-6172, Master's Thesis, AD-608 697.

This thesis is concerned with an investigation into a method of determining the orbital elements of a passive artificial Earth satellite using information obtained from a single coincident satellite observation of short time duration. This method would introduce weighting factors determined, for example, by the accuracy with which the system can measure the parameter in question. This method is then used to study the effect that the addition of Doppler shift and bistatic range measurements have on the accuracy of the resulting orbital elements.

110. Newton, Robert R.,
ERRORS IN LONG-TERM ORBITAL PREDICTION FOR SATELLITE 1961_{01}, Journal of Geophysical Research, Vol. 69, pp. 3619-3624, 1 September 1964, Contract No. NOw-62-0604-c, A64-25119.

This article is a presentation of the results of orbital prediction for the Transit (1961 Omega 1) satellite over periods of 2 to 6 months. The orbits used in the predictions were based on Doppler data obtained within not more than 24 hours. After removal of the drag contribution, the remaining prediction error is found to grow linearly with time, contrary to the theory of Moe. An alternative expression for the growth of error is given. It is shown that the contribution from measurement error is an order of magnitude below the contribution from geodetic errors.

111. Newton, Robert R.,
ORBITAL ELEMENTS FROM DOPPLER TRACKING OF THREE SATELLITES, Journal of Spacecraft and Rockets, Vol. 1, pp. 441-444, July-August 1964, A64-21201.

This article is a presentation of tables of the origin elements of the satellites 1961 Omega 1, 1961 Alpha Eta 1, and 1962 Beta Mu 1. Each of these satellites transmitted four coherent frequencies which were controlled by highly stable oscillators and tracked by Doppler methods. The secular and long-term periodic perturbations of the orbital elements can be analyzed to yield equations of condition connecting zonal harmonics in the Earth's gravitational field. Because of the nature of the radio signals from these satellites, they have been used in studies of radio propagation through the ionosphere and troposphere and in studies of the reflections of radio signals from the Earth's surface. The elements are the eccentricity, the inclination, the argument of the perigee, and the longtitude (right ascension) of the ascending node.

112. Newton, Robert R.,
VARIABLES THAT ARE DETERMINATE FOR ANY ORBIT, ARS Journal, Vol. 31, pp. 364-366, March 1961, A61-4755.

This is a navy-supported presentation of a coordinate system for cases of small eccentricity and small inclination. The system is capable of handling any orbit without indeterminacy, even when making the transition from bound to unbound orbits.

It is shown that the rectangular components of the angular momentum vector and of the "eccentricity vector" form a set of six variables that specify the geometry of any orbit. Only five of these are independent for a given orbit, but there is no particular one that can be eliminated for all orbits, without indeterminacy. The time derivatives of these variables, and important transformations involving them, are presented, using both longitude and argument of the latitude as the additional variable needed. Finally, a method of handling the phase of the motion is suggested.

113. Padua University, Italy,
PREDICTION METHODS FOR SATELLITE TRACKING, by Augusto Mammano, 1961, Report No. ESD-TDR-62-189, Contract No. AF 61(052)-295, AD-454 566.

The computation of topocentric coordinates of satellites for a given station, from orbital elements of geographical ephemerides is described. Three cases are discussed: (1) calculation from orbital elements, (2) use of geographical ephemerides, (3) use of geographical ephemerides together with orbital elements, for instruments whose field is small. In the second case, two different methods are proposed: (1) a quick method, based on the use of isogonic projection, plotting the position of the observer relative to the subsatellite path and allowing an accuracy of 1 degree; and (2) a more accurate method which may also be used when the subsatellite point falls outside the area covered by the grid. For the most frequent cases, specimen computation forms are given. These forms allow the determination of topocentric coordinates in less than 15 minutes, by the simple use of a desk calculator.

114. Paetzold, H. K. and Zschorner, H.,
EXPERIENCES WITH RADIO BEARINGS OF ARTIFICIAL SATELLITES, in Space Research III; Proceedings of the Third International Space Science Symposium, Washington, D. C., 2-8 May 1962, Committee on Space Research— COSPAR and the U. S. National Academy of Sciences, Amsterdam, Holland, North-Holland Publishing Co., New York, Interscience Publishers Division, John Wiley and Sons, Incorporated, 1963, pp. 247-252, A63-19519.

This is an examination of the effect of ionospheric inhomogeneity on the measurement of the azimuth distance and height elevation above the horizon for a satellite. Considerable discrepancy between the measured and calculated values is found and analysis of this leads to information on the inhomogeneities which exist in the upper atmosphere.

115. Pfeiffer, Carl G.,
GUIDANCE OF UNMANNED LUNAR AND INTERPLANETARY SPACECRAFT, American Institute of Aeronautics and Astronautics, Astrodynamics Conference, New Haven, Connecticut, Paper 63-399, 12 pp., 19-21 August 1963, Contract No. NAS 7-100, A63-21716.

This is a description of mathematical techniques for accomplishing Earth-based guidance of unmanned lunar and interplanetary spacecraft. The orbit determination and guidance correction aspects of the problem are developed from linear perturbation techniques well known in exterior ballistics problems. The treatment of correlated noise on the orbit determination data, a policy for determining when to perform impulsive guidance corrections to the orbit, guidance phases of a typical interplanetary mission, computation of the differential coefficients and the effect of second-order errors, a technique for optimal guidance of powered-flight trajectories, and the relationship of spacecraft and launch vehicle guidance analysis are considered.

116. Pines, Samuel,
VARIATION OF PARAMETERS FOR NEAR CIRCULAR AND LOW INCLINATION ORBITS, Appendix - DERIVATION OF PERTURBATIONS DERIVATIVES, IAS Annual Meeting, 29th New York, New York, Paper 61-7, 12 pp. 23-25 January 1961, A61-1303.

This is a presentation of a method for determining the instantaneous position by the evaluation of slowly varying elements of an osculating two-body conic section. Ambiguities introduced in other variational methods, when considering orbits of low eccentricity and low inclination, are avoided by the use of a set of parameters which describes the two-body conic section without specific reference to the pericenter position, the orbital inclination, or the ascending node. An additional perturbation equation for the rapidly changing mean anomaly is also avoided. Parameters used are initial position and velocity vectors in the osculating orbit plane, whose positions are related to the instantaneous position and velocity through Kepler's equation.

117. Pinkham, Gordon,
REFERENCE SOLUTION FOR LOW THRUST TRAJECTORIES, ARS Journal, Vol. 32, pp. 775 and 776, May 1962, A62-7394.

This is a NASA-sponsored analysis of the trajectory equations for a low-thrust rocket when the thrust is tangential and varies nearly inversely with the square of the radius from the central body. The variation in the thrust magnitude is chosen so that the solution possesses as many arbitrary constants as the order of the system of differential equations governing the motion. Thus an Encke or variation of parameters analysis of neighboring trajectories is practicable.

118. Proskurin, V. F. and Batrakov, V.,
FIRST-ORDER PERTURBATIONS IN THE MOTION OF EARTH SATELLITES DUE TO OBLATENESS OF THE EARTH, (Iskusstvennye Sputniki Zemli, No. 3, pp. 32-38, 1959), U.S., NASA TT F-45, 12 pp., November 1960, A61-2799 (Translation).

This is a presentation of an analytical theory for artificial Earth satellites, on the assumption that the oblateness of the planet is small enough so that the perturbation function in powers of the oblateness can be limited to the term containing only the first powers of the oblateness of the Earth. This portion of the perturbation function is expanded in powers of the eccentricity. Integration of the ordinary Lagrange equations yields analytical expressions of the first-order perturbations relative to the oblateness of all the elements of the orbit, accurate to the fourth degree of the eccentricity inclusive.

119. Proskurin, V. F. and Batrakov, V.,
PERTURBATIONS IN THE MOTION OF ARTIFICIAL SATELLITES DUE TO THE OBLATENESS OF THE EARTH, (Bulleten' Instituta Teoreticheskoi Astronomii, Vol. 7, No. 7, pp. 537-548, 1960), ARS Journal, Russian Supplement, Vol. 31, pp. 117-125, January 1961, A61-3745 (Translation).

This is a study, based on classical equations of Lagrange, to derive literal expressions for first-order perturbations in the orbit elements of artificial Earth satellites. The expressions are correct to the first power of the Earth's oblateness and up to the fifth power of the orbital eccentricity. The coefficients of these expressions depend on the inclination of the orbit by way of trigonometric polynomials. More accurate

expressions are given for secular first-order perturbations in the longitude of the node, in the argument of the perigee, and in the mean anomaly. The secular motion of the node is determined with allowance for second-order perturbations due to the Earth's oblateness. A numerical example is presented that illustrates the comparative magnitude of the perturbations.

120. Radzievskii, V. V. and Artem'ev, A. V., THE INFLUENCE OF SOLAR RADIATION PRESSURE ON THE MOTION OF ARTIFICIAL EARTH SATELLITES, (Astronomicheskii Zhurnal, Vol. 38, pp. 994-996, September-October 1961), Soviet Astronomy, Vol. 5, pp. 758 and 759, March-April 1962, A62-5322 (Translation).

This is a study of the influence of solar radiation pressure on the variation of the perigee distance of artificial Earth satellites. A solution is given for a more general case than that considered by Musen, the Earth's shadow being taken into account. The adopted method of computation is simpler than that of Musen and is sufficiently reliable for orbits with a low eccentricity. It is shown that solar radiation pressure can give rise to a decelerating effect equivalent to a frictional deceleration in a medium with density of the order of 10^{-16} g/cm^3. It is, therefore, concluded that estimates of atmosphere density at great altitudes obtained from dynamical considerations are incorrect if radiation pressure is neglected.

121. Richards, P. B., PRELIMINARY ORBIT DETERMINATION OF A NONTRANSMITTING SATELLITE USING THE DOPLOC TRACKING SYSTEM, ARS Journal, Vol. 31, pp. 1729-1738, December 1961, A62-2051.

This is an Army-sponsored derivation of equations which relate passive satellite Doppler tracking data to range, speed, and time parameters at closest approach. These determine an ellipsoid whose foci are the transmitter and receiver stations. The satellite lies on this ellipsoid, and its trajectory is tangent to the surface. The satellite position and velocity components at closest approach are then calculated on a digital computer using Doppler and limited angle information provided by the DOPLOC tracking system.

122. Royal Aircraft Establishment, Farnborough, England, A PEGASUS COMPUTER PROGRAMME FOR ESTIMATING ERRORS IN THE EPHEMERIS OF A SATELLITE, WITH AN APPLICATION TO ARIEL 1, by R. H. Gooding, Report No. RAE-Technical Note No. Space 37, AD-420 396.

A computer program is described by means of which the errors in computing the position of a satellite in orbit can be estimated from the convariance matrix of errors in the orbital parameters. The program is used to show that orbital parameters of Ariel 1 derived from minitrack data are good enough for the position of Ariel to be computed to within 1 kilometer. Had observations from a modified Schmidt camera been available, in addition, position computation would have been about twice as accurate. With two such cameras, one in England and one in Australia, position computation to within 200 meters would have been possible.

123. Royal Canadian Air Force, Ottawa, Ontario, Canada, A PRELIMINARY STUDY OF THE ACCURACY OF DETERMINATION OF SATELLITE ORBITS, by D. W. Mclimont, August 1962, Report No. RCAF-COR/DSE Memorandum 62/6, AD-419 266.

The results are described of a study of the accuracy of determination of satellite orbits, using a single ground based sensor. The effects of accuracy of sensor measurement and of amount of observed data upon the accuracy of predicting future target position are analyzed and discussed.

124. Royal Canadian Air Force, Ottawa, Ontario, Canada, DSE-496L MODEL FOR STUDY OF REQUIREMENTS FOR ACCURACY IN SATELLITE ORBITAL DETERMINATION AND PREDICTION, by E. C. Kehayas, September 1962, Report No. RCAF-COR/DSE Memorandum 62/9, AD-419 267.

A cooperative program dealing with the analysis of space surveillance systems has been undertaken by the Directorate of Systems Evaluation, RCAF, and 496L Systems Project Office, USAF. This report describes the first study under this program in the area of satellite tracking. The study is directed toward the investigation of factors involved in the accuracy of prediction of future position of the vehicle observed.

125. Sarychev, V. A.,
EFFECT OF EARTH'S OBLATENESS OF THE ROTATIONAL MOTION OF AN ARTIFICIAL EARTH SATELLITE, (Iskusstvennye Sputniki Zemli, No. 6, pp. 3-10, 1961), ARS Journal, Russian Supplement, Vol. 32, pp. 834-838, May 1962, A62-7390 (Translation).

This article is a derivation of approximation formulas for three independent angles ψ , θ , T , which determine the orientation of a satellite relative to the orbital coordinates of its center of mass. These formulas involve the Earth's oblateness, the small eccentricity of the orbit, and the principal moments of inertia of the satellite. The effects of these quantities (oblateness, eccentricity) on the stability of the rotational motion of a satellite are shown for a typical case.

126. Sauer, C. G., Jr.,
PERTURBATIONS OF A HYPERBOLIC ORBIT BY AN OBLATE PLANET, ARS Journal, Vol. 32, pp. 714-717, May 1962, A62-7395.

This is a NASA-sponsored derivation of the hyperbolic orbital elements of a vehicle as functions of the initial osculating elements. The assumptions are made that atmospheric drag is absent and that the gravitational potential of the planet may be represented adequately by the principal term and the second harmonic. An example of an Earth-escape mission is presented in which comparison is made between calculated orbital perturbations and results from a numerical integration of the equations of motion.

127. Savet, P. H.,
SATELLITE ORBITS DERIVED FROM A GRAVITATIONAL MODEL OF THE EARTH, Planetary and Space Science, Vol. 7, pp. 154-163, July 1961, A62-2069, (AFBMD/STL Symposium on Advances in Ballistic Missile & Space Technology, 4th, Los Angeles, California, 24-27 August 1959).

This is a study of irregularities in the orbits of so-called close satellites which are caused by the finite mass distribution of the Earth. It is shown that a faithful gravitational picture of the Earth may be offered by means of a fictitious mass distribution confined to the equatorial plane of the Earth. This solution, first derived by Maxwell in an analogous electrostatic problem, is extended to gravitational phenomena, and a family of actual equipotential surfaces are derived.

128. Schütte, Karl,
THE PHYSICAL AND ASTRONOMICAL PRINCIPLES OF SATELLITE AND SPACE FLIGHT. II (PHYSIKALISCHE UND ASTRONOMISCHE GRUNDLAGEN DES SATELLITEN - UND DES WELTRAUMFLUGS, II), VDI Zeitschrift, Vol. 106, pp. 629-634, May 1964, A64-20209 (In German).

This is a brief discussion of three- and n-body problems and their periodic solutions. The necessity of using computers in orbit compilations is indicated, and equations describing the principles of rocket propulsion are developed. Problems associated with orbit determination and correction, special artificial Earth satellites, and flight trajectories to the Moon, Mars, and Venus are then discussed.

129. Seddon, J.,
SPACE DYNAMICS, Spaceflight, Vol. 5, pp. 192-197, November 1963, A64-11387.

This is a review of basic principles for analyzing the motions of space vehicles and satellites. Briefly treated are Kepler's laws, Newton's law of gravitation, the principles underlying coplanar orbital transfers (including Hohman transfers), changes of orbital plane, waiting and timing maneuvers, and the relationship between rocket velocity increments and fuel expenditure.

130. Sedov, L. I.,
ORBITS OF SPACE ROCKETS IN THE DIRECTION OF THE MOON, (Iskusstvennye Sputniki Zemli, No. 5, p. 3, 1960), Planetary and Space Science, Vol. 8, pp. 107-116, 1961, A62-2068 (Translation).

This is a presentation of practical data with regard to the orbits of the Soviet space probes Lunik I, II, and III. The performance of the vehicles is discussed on the basis of a theoretical analysis of the laws of motion of vehicles in cosmic space, and of calculations based on these relationships.

131. Shapiro, George,
THREE DIMENSIONAL ORBITS WITH FIXED LOW THRUST, Westinghouse Electric Corporation, Air Arm Division, Rep. (AFOSR 2610), 13 pp. 11 May 1962, A62-8359.

This is an extension of a previous analysis to the three dimensional case of a satellite in orbit with an additional steady, low thrust in a fixed direction. The method of Krylov-Bogoliuboff is applied, and closed form solutions to the equations of the first approximation are obtained. As in the planar case, the major axis remains constant. Unlike the planar case, escape does not occur and the eccentricity oscillates between limits determined by the initial conditions. The applicability of the analysis to the behavior of a satellite for solar observation is shown.

132. Shapiro, Irwin I.,
THE PREDICTION OF SATELLITE ORBITS, in Dynamics of Satellites, Proceedings of the IUTAM Symposium, Paris, France, 28-30 May 1962, New York, Academic Press, Incorporated, 1963, pp. 257-312, A64-12678.

This is a development and application of a perturbation method to the prediction of orbits of Earth satellites that are disturbed by various external forces. The theory of resonances and stable orbit configurations, possible when sunlight pressure is important, are also analyzed. Finally, experiments to determine the magnitude of perturbing forces, such as charge drag, are described.

133. Small, Huntington W.,
SATELLITE MOTION AROUND AN OBLATE PLANET, American Institute of Aeronautics and Astronautics, Astrodynamics Conference, New Haven, Connecticut, Paper 63-393, 14 pp., 19-21 August 1963, A63-21711.

This is a derivation, from basic principles, of a solution to the problem of the motion of a satellite around a rotationally symmetric planet. An efficient set of equations for the programming of the solution is provided, and comparisons with numerical integrations are included. To obtain a general replacement for numerical integration, the variables and integration constants are chosen to eliminate the singularities for zero eccentricity and at the critical inclination angle. They make the solution usable for hand computations and as a reference orbit for studying drag perturbation, definitions of the short-period terms in the elements are chosen to emphasize the natural symmetry in the elements used, thereby simplifying algebraic expansions of the solution.

134. Smyth Research Associates, San Diego, California,
TARGET ACCURACY EXPERIMENT, by L. R. Hughes, J. H. Gibbs, and L. A. Morgan, February 1964, Report No. RADC-TDR-63-460, Contract No. AF 30(602)-2084, AD-432 414.

The Earth's atmosphere distorts the radio view of space vehicles as seen from the Earth's surface. The limitations placed on one's ability to position and locate objects in space as a consequence of this distortion is the subject of the reported investigations. A detailed experimental program was pursued to measure particularly the elevation angle errors incurred in making space target measurements from the Earth's surface when viewing near the horizon. Signals originating in artificial Earth satellites were viewed through the distorting atmospheric medium and analyses performed to define the observed distortions as a function of space, frequency, and time.

135. Sochilina, A. S.,
DETERMINATION OF ORBITS BASED ON VISUAL AND PHOTOGRAPHICAL OBSERVATIONS, in Dynamics of Satellites, Proceedings of the IUTAM Symposium, Paris, France, 28-30 May 1962, New York, Academic Press, Incorporated, 1963, pp. 202-204, A64-12672 (Translation).

This is a preliminary calculation of orbits of the Earth's artificial satellites by means of visual and photographic observations. The orbits obtained from visual observations are used for the computation of ephemeris, also as preliminary ones for the computation of precise orbits. The determination of orbits from visual observations has been made for all Soviet satellites. Orbits based on visual observations are determined at intervals of 10-15 days; orbits based on photographic observations are computed at intervals of 1-2 days, with rather satisfactory accuracy. The obtained orbit can be improved only after taking into account tesseral harmonics and more precise coordinates of the observation station.

136. Soong, T. T.,
OUT-OF-PLANE PERTURBATIONS OF A CIRCULAR SATELLITE ORBIT, AIAA Journal, Vol. 1, pp. 2862 and 2863, December 1963, Contract No. NAS 7-100, A64-11767.

This is an investigation of the validity of the first-order approximation for the out-of-plane motion of a long-lifetime satellite. It is shown in the case of a circular orbit that the effect of small deviations in inplane parameters on the statistics of the out-of-plane motion may become significant, indicating the need of considering higher-order terms in certain cases.

137. Space Technology Laboratories, Incorporated, Redondo Beach, California,
ELECTRONIC SYSTEMS DIVISION PRECISION ORBIT DETERMINATION PROGRAM, April 1964, Report No. ESD-TDR-64-452, Contract No. AF 19(628)-594, AD-607 053.

The report covers certain technical and mathematical considerations which are germane to the accuracy of ESPOD. Particular emphasis is given to numerical integration process, the calculation of the vernal equinox, and the interpretation of the Earth potential model.

138. Spies, Otto R.,
POSITION AND VELOCITY ESTIMATES BY TRAJECTORY RECTIFICATION, American Institute of Aeronautics and Astronautics, Astrodynamics Conference, New Haven, Connecticut, Paper 63-427, 25 pp., 19-21 August 1963, A63-21736.

This is a presentation of a global method of estimating the true position and velocity of a particle at some specified instant from a succession of its observed, not too widely spaced, positions (measured directly by radar or determined indirectly in some other way). The method utilizes fully the a priori knowledge of the integral equations of motion of the particle, and may be used in problems of trajectory determination, prediction, or retrodiction, and also in an inverse mode, for refinement of these equations. In contrast to the inherently deterministic, local, differential methods, this global, integral method is inherently probabilistic. While the former are well-suited for evaluation of accurate, though perhaps scanty observational data, the latter is especially suited for evaluation of inaccurate, but redundant data.

139. Spies, Otto R.,
TWO NOTES IN ORBIT THEORY, in 12th International Astronautical Congress, Proceedings, Vol. 1, Washington, D. C., 1-7 October 1961, New York and London, England, Academic Press, Incorporated, 1963, pp. 121-130, A63-21246.

This is a presentation of closed-form solutions to the problem of motion of a free particle in: (1) the combined gravitational fields of two-point-symmetrical mass distributions, and (2) a meridian plane of the gravitational field of an oblate spheroid. First, the existing method of solution of the two-dimensional problem of motion in a meridian plane of the axisymmetric joint field is recapitulated. Then, the closed-form solution of the three-dimensional problem is obtained by the use of prolate spheroidal coordinates. In the special case when one of the two mass distributions is absent, this solution represents a Keplerian orbit. The special case is also considered of the three-dimensional problem of motion in the field of an oblate spheroid solved by Vinti, when the particle moves in a meridian plane of that axisymmetric field.

140. Stewart, Clarence H. and Vincent, Gary J., RADAR-TRACKING ACCURACY INCREASED, Electronics, Vol. 37, pp. 73-75, 4 May 1964, A64-21062.

This is a description of a method for estimating the permittivity of the atmosphere, a major factor in radar-tracking errors, by using a microwave refractometer. The construction, operating principles, and calibration of the refractometer, which is stable enough to perform absolute rather than relative measurements, are described. Ways in which the refractivity data could be used to increase the accuracy of radar techniques are considered.

141. Struble, R. A., AN APPLICATION OF THE METHOD OF AVERAGING IN THE THEORY OF SATELLITE MOTION, Journal of Mathematics and Mechanics, Vol. 10, pp. 691-704, September 1961, A61-8732.

This is an Army-sponsored study of satellite motion using a method similar to that of Krylov-Bogoliubov-Mitropolski. The reduced nonlinear equations are integrated in closed form and the complete solution is expressed in terms of standard elliptic integrals. The solution reveals the secular characteristics of the motion without recourse to perturbational procedures.

142. Struble, R. A., THE GEOMETRY OF THE ORBITS OF ARTIFICIAL SATELLITES, Archives of Rational Mechanics and Analysis, Vol. 7, No. 2, pp. 87-104, 1961, A61-8734.

This is an Army-sponsored presentation of a novel approach to the study of satellite orbits, with particular reference to the basic geometry and other aspects of satellite motion which are important in satellite technology. The motion of the orbital plane as a rigid body is introduced, and a nonelliptical orbit motion in this plane is defined. The plane orbit so defined has a valuable feature of representing a succession of satellite positions, thus revealing the true motion of the satellite. An analytical treatment yields a completely general second-order theory of Earth satellite motion, suitable for engineering purposes. Particular attention is directed to the apsidal motion of the orbit and the concomitant resonance effects at the critical orbit inclination. The basis nonlinear features of the apsidal motion, not accounted for in earlier theories, are included in the analysis so as to produce a theory valid for all angles of orbit inclination.

143. Struble, R. A. and Campbell, W. F.,
THEORY OF MOTION OF A NEAR EARTH SATELLITE, ARS Journal, Vol. 31, pp. 154 and 155, January 1961, A61-3726.

This is an Army-sponsored presentation of first-order and second-order solutions of the equations of motion of a near Earth satellite. The solutions are completely general without restrictions on eccentricity or orbital inclination. Though the traditional orbital plane of astronomy is employed, it is shown that a nonelliptical orbit in this plane displays the basic geometry more readily than would the traditional osculating ellipse.

144. Sun, Fang Toh,
ON THE HODOGRAPH METHOD FOR SOLUTION OF ORBIT PROBLEMS. Appendix - DERIVATION OF THE CORRELATION FORMULAS, in 12th International Astronautical Congress, Proceedings, Vol. 2, Washington, D. C., 1-7 October 1961, New York and London, England, Academic Press, Incorporated, 1963, pp. 879-915, A63-21296.

The fundamentals of hodographs for orbital motion are presented, and their various applications to the analysis of orbit characteristics, the derivation of orbital relations, and the solutions of some specific orbit problems are illustrated with examples. Two versions of the hodograph are employed and compared: one is the conventional hodograph using the velocity coordinates along two orthogonal directions fixed in the orbit plane, and the other is the special hodograph using the radial and transverse velocity coordinates. In an inverse-square central force field both hodograph transformations have the advantage of mapping a conic orbit in the physical plane to a circle in the hodograph plane, thus reducing the kinematic problems of orbital motion to the geometrical problems of circles.

145. System Development Corporation, Santa Monica, California, A MATHEMATICAL TECHNIQUE FOR ESTIMATING SATELLITE LATITUDE CROSSING TIME, by J. Aldana, April 1963, Report No. TM-L1202, Contract No. AF 19(628)-1648, AD-405 341.

The possibility that the rate of the argument of latitude (historically, the astronomer's terminology for the in-orbit angle measured from the ascending node) might be utilized to yield a measure of the latitude crossing time is considered. This document discusses a method of utilizing the true anomaly rate, which essentially equals the argument of latitude rate, when other and perhaps not well defined information exists. These other data include: at least one reasonably accurate station datum set which includes time, elevation, azimuth, and range; orbital inclination; orbital period (to within approximately 4 minutes for low orbits); and orbit eccentricity (rough estimate).

146. System Development Corporation, Santa Monica, California, SPECIAL PERTURBATION TECHNIQUES APPLICABLE TO SPACETRACK, by P. Chambliss, Jr., and J. Stanfield, July 1964, Report No. ESD-TDR-64-533, Contract No. AF 19(628)-1648, AD-611 283.

This report describes in detail three special techniques which can be specifically applied in the spacetrack system to determine the motion of an artificial satellite under the influence of perturbing accelerations. These techniques are: variation of parameters, Cowell's method, and Encke's method.

147. Tapley, B. D. and Lewallen, J. M., SOLAR INFLUENCE ON SATELLITE MOTION NEAR THE STABLE EARTH-MOON LIBRATION POINTS, American Institute of Aeronautics and Astronautics, Aerospace Science Meeting, New York, New York, Preprint 64-68, 8 pp., 20-22 January 1964, A64-12756.

This is a study of the motion of a space vehicle in the vicinity of the stable Earth-Moon libration points, using a model which includes the perturbing effects of the gravitational attraction and the radiation pressure of the Sun. The Earth and the Moon are assumed to move in circular orbits about their mass centers, and the Earth-Moon orbit plane is assumed to be inclined at an angle of 5 degrees 9 minutes to the Ecliptic. The differential equations of motion in a libration-point centered coordinate system are integrated numerically to determine the behavior of the vehicle. The results of the investigation indicate that when the effects of the Sun are included, the natural motions of a vehicle placed initially at the libration points L_4 or L_5 will not remain near the respective point. Although the vehicle does move on a trajectory about the libration point for at least 700 days, the influence of the Sun causes the vehicle to move through wide departures from the libration point. The effects of the solar radiation pressure for several satellite area-to-mass ratios are studied, and the impulse requirements necessary to force a vehicle to remain at L_4 or at a point near L_4 are determined.

148. Taratynova, G. P.,
NUMERICAL SOLUTION OF EQUATIONS OF FINITE DIFFERENCES AND THEIR APPLICATION TO THE CALCULATION OF ORBITS OF ARTIFICIAL EARTH SATELLITES, (Iskusstvennye Sputniki Zemli, No. 4, pp. 56-85, 1960, ARS Journal, Russian Supplement, Vol. 31, pp. 976-988, July 1961, A61-7793 (Translation).

This is a presentation of two methods (Runge-type and Adams-type interpolation) for the solution of the equations of finite differences. A comparison is made between the two methods for limiting cases. An application is made to the calculation of the orbit of a satellite having parameters similar to those of Sputnik I.

149. Vassy, E.,
ETUDE DE L'EMISSION RADIOELECTRIQUE DES SATELLITES ARTIFICIELS, Astronautica Acta, Vol. 7, Fasc. 2-3, pp. 237-246, 1961, A61-7778 (In French).

This is a description of a method for measuring the Doppler-Fizeau effect. Although long and involved, the method is precise and well adapted to satellite tracking. A method for simultaneous measurement of the Doppler-Fizeau effect and the amplitude is also described. Experimental results obtained from the satellite 1960 Eta 2 are presented as pen traces. Ionospheric inhomogeneities and perturbing phenomena are discussed and the possible application of the method to the measurement of ionospheric absorption is noted.

150. Vinti, J. P.,
INTERMEDIARY EQUATORIAL ORBITS OF AN ARTIFICIAL SATELLITE, U. S., NBS Rep. 7345 (AFOSR 1480), 20 pp., 2 October 1961, A62-989.

This is an extension of a previous analysis of drag-free motion of an artificial satellite in the gravitational field of an oblate planet, to remove a certain restriction on the orbital inclination for a near-earth orbit. It is shown that many of the formulas for the periodic terms may be simplified when the orbit is equatorial or almost so. The results are in good agreement with those obtained by a direct two-dimensional solution for a purely equatorial orbit.

151. Vinti, J. P.,
THEORY OF AN ACCURATE INTERMEDIARY ORBIT FOR SATELLITE ASTRONOMY, Journal of Research, Section B, Mathematics and Mathematical Physics, Vol. 65B, pp. 169-201, July-September 1961, A61-9718.

This is a USAF-supported derivation of an accurate intermediary orbit of an artificial satellite of an oblate planet. The drag-free motion takes place under the action of a gravitational potential which fits the even zonal harmonics exactly through the second and approximately through the fourth, in the case of the Earth. This potential leads to separability of the Hamilton-Jacobi equation. Two alternative sets of orbital elements are set forth. The final solution is given in terms of certain uniformizing variables, whose periodic terms are correct through the second order in the oblateness parameter and whose secular terms are exact, for the intermediary orbit. These exact solutions for the secular terms are expressed by means of certain rapidly coverging series, with complete avoidance of elliptic integrals of the third kind.

152. Vinti, J. P.,
ZONAL HARMONIC PERTURBATIONS OF AN ACCURATE REFERENCE ORBIT OF AN ARTIFICIAL SATELLITE, Journal of Research, Section B, Mathematics and Mathematical Physics, Vol. 67B, pp. 191-222, October-December 1963, A64-12167.

This is a NASA-supported modification of a previously developed theory for an accurate reference orbit of an artificial satellite, to include the effects of zonal harmonic perturbations. Delaunay variables are introduced by means of certain linear combinations of the action variables, along with their canonical conjugates. Application of the von Zeipel method then permits the most important zonal harmonic perturbations to be calculated. These arise from the third, with coefficient J_3, and the residual fourth, with coefficient $J_4 + J_2^2$. The accuracy of the secular and short-periodic effects is through terms of order J_2^2 and that of the long-periodic effects is through terms of order J_2. Since the reference orbit itself, with its exact secular terms, takes care of all but 0.5 percent of the deviation of the Earth's gravitational field from spherical symmetry, the overall secular accuracy of the final orbit surpasses that of other second order theories. The results are compared with those of Kozai.

153. Vonbun, F. O.,
ANALYSIS OF THE "RANGE AND RANGE RATE" TRACKING SYSTEM, Appendix A - DETAILS OF THE SATELLITE POSITION ERRORS. Appendix B - DETAILS OF THE SATELLITE VELOCITY ERRORS, U. S., NASA TN D-1178, 59 pp., February 1962, A62-5308.

This is a discussion of the Range and Range Rate high-precision satellite tracking system, with particular attention to position and velocity errors. The nature of these errors is studied, and it is shown that (1) they are small when moderate measuring accuracies are used; (2) the time-synchronization requirements are not severe; (3) the position of the satellite with respect to the ground station does not have too significant an effect upon the velocity and position errors; and (4) uncertainties in the ground-station position have a large influence upon these errors.

154. Ward, G. N.,
ON THE SECULAR VARIATIONS OF THE ELEMENTS OF SATELLITE ORBITS, Royal Society, London, England, Proceedings, Series A, Vol. 266, pp. 130-142, 27 February 1962, A62-5323.

This is a discussion of the perturbing forces which cause a near-Earth satellite to depart from a Keplerian elliptical orbit. It is shown that a simple and rigorous theory, valid for all values of orbital eccentricity less than unity, can be constructed for the orbital perturbations of such satellites. The analysis is in vector form, and the orbital geometry is therefore described in terms of the angular momentum, direction of perigee, and eccentricity, from which other elements can be readily obtained. The method is applied briefly to the first-order effects of the Earth's oblateness, and in more detail to the effects of atmospheric resistance. Certain integrals occurring in the theory of atmospheric resistance are evaluated as asymptotic series whose first two terms are sufficient for accurate determination of the perturbations.

155. Wengert, R. E. and Jones, J. F.,
ORBIT DETERMINATION ACCURACIES USING SYSTEMATIC ERROR ADJUSTMENTS, American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D. C., Paper 64-395, 15 pp., 29 June-2 July 1964, A64-21852.

This is a consideration of the potential effects involved in using different processing models and different error-analysis modes for orbit estimation. Three generic types of models are discussed: (1) the error model, which described the uncertainties of error sources involved in predicting the numerical values of test observations; (2) the data processing model, which determines the data processing procedure and is, generally, a simplification of the error model; and (3) the error analysis model, which determines the expected accuracy associated with a given processing model. Two orbit-determination systems are examined. The first system uses one-way Doppler measurements obtained on a single satellite pass over a complex of stations. The results indicate that adjustment of major systematic error parameters can nearly eliminate their effects and greatly improve the orbit determination accuracy. The second system uses two tracking sites with radar position and interferometer rates being measured from each. Data is postulated from an orbit which passes twice over the first station and once over the second station. Accuracies of orbit determination are presented for two orbit altitudes and two levels of radar accuracy. Model parameter improvements are also presented.

156. Woodman, R. F.,
IRREGULAR REFRACTION OF ARTIFICIAL SATELLITE SIGNALS OBSERVED AT ANCON, PERU, in Advances in Space Research; Proceedings of the 1st Inter-American Symposium on Space Research, Buenos Aires, Argentina, November 1960 (A65-17964 08-30), (Symposium sponsored by the Argentine National Commission on Space Research.) Oxford, England, Pergamon Press, Ltd.; New York, Macmillan Company, 1964, pp. 331-344, A65-17982.

This is an observation of deviations on the order of 1 degree between the radio positions and the true positions of satellites with rapid apparent East-West movement. These deviations were noted at the NASA satellite tracking station at Ancon, Peru. The nature of this phenomenon and its possible origin are discussed. A strong correlation between the occurrence of this phenomenon and the incidence of "Spread F" in the ionosphere is shown.

157. Woodward, P. M.,
THE CALCULUS OF RADAR OBSERVATIONS, in Avionics Research: Satellites and Problems of Long Range Detection and Tracking, AGARD Avionics Panel Meeting, Copenhagen, Denmark, 20-25 October 1958, Papers (AGARDograph No. 40), London, England, New York, Pergamon Press, 1960, pp. 6-11, A61-1724.

Not abstracted.

158. USAF, Aerospace Research Laboratory, Wright-Patterson Air Force Base, Ohio,
FEASIBILITY OF REAL-TIME TRACKING-COMPUTING-PREDICTING SYSTEM FOR SPACE VEHICLES, October 1960, Report No. WADD TR-60-215, A61-7781.

This is an analysis of the feasibility of systems for the real-time tracking, computing, and predicting of space vehicles. The requirements for systems using a single station to acquire and observe known Earth satellites are given. To obtain higher accuracy, optical sensors are considered. For performing an operation in real time, an image tube with automatic read-out into a digital computer is indicated. An analysis is given to demonstrate the extent to which the orbital data on an Earth satellite can be corrected by means of angular data from a single station observing a single pass of the vehicle. Computational results produced with optical data from actual observations of an Earth satellite are included to confirm the analytical conclusions. Three types of systems are proposed as solutions, and, as a result of the analysis, two of the three solutions are found to be feasible.

159. Wyatt, Stanley P.,
THE EFFECT OF TERRESTRIAL RADIATION PRESSURE ON SATELLITE ORBITS, in Dynamics of Satellites; Proceedings of the IUTAM Symposium, Paris, France, 28-30 May 1962, New York, Academic Press, Incorporated, 1963, pp. 180-196, A64-12670.

This is a discussion of the perturbations caused by terrestrial radiation in the period and eccentricity of a close satellite. A variety of approximate models of the radiation are constructed, and the secular perturbations of orbital period and eccentricity are calculated. The preliminary conclusions are that the infra-red radiation and the specular part of the albedo radiation cause only negligible effects. The diffuse part of the albedo radiation, on the other hand, appears in a general way to affect the dynamical elements. The secular perturbations are about 10 or 15 percent as large as those arising from the force of direct sunlight. In a general way, their effects tend to imitate those of direct solar radiation pressure. Thus far it has not been possible to find clear evidence of terrestrial pressure in the orbital data on individual satellites because of uncertainties in their average A/m ratios and in their own reflection characteristics.

160. Zehle, Heinz and Giloi, Wolfgang, THE SOLUTION OF OPTIMIZATION PROBLEMS IN SPACE-FLIGHT TRAJECTORIES OF SMALL THRUST ACCELERATION WITH THE AID OF AN ANALOG COMPUTER (ÜBER DIE LÖSUNG VON OPTIMALISIERUNGSPROBLEMEN BEI RAUMFLUGBAHNEN KLEINER SCHUBBESCHLEUNIGUNG MIT HILFE DES ANALOGRECHNERS), in Association Internationale Pour le Calcul Analogique, Colloque International des Techniques de Calcul Analogique et Numerique en Aeronautique, Proceedings, Liege, Belgium, 9-12 September 1963 (A65-19381 09-11), (Symposium sponsored by the Université de Liège, Conseil National de la Politique Scientifique, Ministère des Affaires Economiques, Ministère des Communications, Ministère de la Défense Nationale, and Ministère de l'Education Nationale et de la Culture.) Brussels, Presses Académiques Européennes, 1964, pp. 498-506, A65-19432 (In German).

This is a mathematical analysis of spaceflight trajectories of small thrust acceleration. The equations of motion of the spacecraft are presented. The variational problem is described and reduced to the solution of a system of boundary-value equations with the aid of the Lagrange function. The first approximation is given, and the solution is performed on an analog computer. Wiring diagrams of the computational program are included. The results are shown in a number of graphs and diagrams. The accuracy of the computation is discussed.

161. Zirm, Rudolph R.,
VARIATIONS IN DECAY RATE OF SATELLITES 1963-21,
Journal of Geophysical Research, Vol. 69, pp. 4696 and 4697,
1 November 1964, A65-10348.

This is a study of anomalous variations of the decay in the period of the satellites 1963-21A, B, C, D, E, and F. The perigee of these objects was approximately 170 kilometers, the apogee approximately 860 kilometers, with inclinations of about 69 degrees. All observations were made using data from the US Naval Space Surveillance System, the coverage of which is essentially a vertical plane extending across the southern United States along a great circle of 33.57-degree inclination. The period was determined from the times of system penetration on successive passes of a particular satellite corrected for the latitude difference of the two observations. The noise in the decay curves was studied by the method of least squares and found to be approximately sinusoidal with a period of 9 days and an amplitude of approximately 2 seconds. Similar variations during this interval have been observed in the period of Explorer 17 (1963-9A) with a perigee altitude of 262 kilometers. Jacchia correlated these with the occurrence of magnetic storms at this time of year.

Section III. PROGRAMS AND SATELLITE SYSTEMS

This section includes tracking systems; missile ranges; and plans, experiments, and research requirements.

162. Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio,
MULTISATELLITE CONTROL, by Aloysius Gerald Casey, August 1964, Report No. AFIT-GA/EE/64 1, Master's Thesis, AD-607 033.

The thesis provides a method of controlling a system of orbiting satellites through a net of servicing ground stations. The problem is defined and a solution based on a dual view of the time spectrum is selected, that is, the vital service requirements are scheduled horizontally across the scheduling period, while the routine reports are treated vertically in time. The thesis includes a computer program written in the Fortran IV language and based on the logical development explained in the thesis. A 10-satellite and a 5-ground station example problem is presented.

163. Author Unknown,
INTERIM DEFINITIVE ORBIT FOR THE SATELLITE 1959 ALPHA VANGUARD-II, U. S., NASA TN D-411, 165 pp., September 1960, A61-544.

This is a summary of interim definitive ephemeris for the orbit of satellite 1959 Alpha, Vanguard-II during the period of its radio lifetime. Certain position information indicating accuracies for the orbital arcs underlying the ephemeris is presented. The detailed ephemeris information is presented in tabular form, giving the latitude and longitude of the sub-satellite point and the satellite height for each minute of time.

164. Author Unknown,
UNITED STATES SPACE SCIENCE PROGRAM: REPORT TO COSPAR, COSPAR, 4th International Space Science Symposium, Warsaw, Poland, Paper, 303 pp., 3-11 June 1963, A63-22777.

This is a review of U. S. space-science activities for 1962 and early 1963. Coverage in the following fields is included: (1) astronomy; (2) solar physics; (3) energetic particles and fields; (4) the ionosphere; (5) planetary atmospheres and meteorology; (6) planetology; (7) biological studies; (8) celestial mechanics, trajectory studies, geodesy, and gravity; (9) laboratory astrophysics; (10) communications satellites; (11) new developments in NASA's tracking and data acquisition system; and (12) international activities of the U. S. National Academy of Sciences and of NASA. Also included, in appendices, are: (a) a summary of U. S. launchings in 1962 and the planned NASA flight schedule, (b) a list of titles in the IGY racket and satellite report series, (c) a list of journals in which U. S. space research reports are generally published, (d) space-related research supported by the National Science Foundation, and (e) a bibliography of material on the space sciences published in the U. S. in 1962. Specific topics in this bibliography are orbits, trajectories, and other motions; tracking and telemetry; instrumentation and techniques; interaction between space vehicle and medium; gravity and geodesy; atmospheric composition and structure; particles and magnetic fields; meteorites, cosmic dust, and tektites; the Sun; the Moon and the planets; general astronomy; life sciences; and related general topics.

165. Bennett, S. B. and Thomas, L. C.,
THE TELSTAR COMMUNICATIONS SATELLITE EXPERIMENT PLAN, IEEE Transactions on Communication and Electronics, pp. 54-60, January 1964, A64-15839, (Institute of Electrical and Electronics Engineers, Summer General Meeting and Nuclear Radiation Effects Conference, Toronto, Canada, Paper 63-952, 16-21 June 1963).

This is a description of the Telstar experiment plan and objectives. The design of the communications system is described, showing the interrelation between satellite capabilities and ground station requirements. The factors determining the initial orbit and attitude; techniques for predicting satellite position, attitude, and eclipse times; and attitude measurement and control are discussed. Good correlation between predicted and measured satellite attitude is shown. The plan for acquisition and command tracking of the satellite, and a typical operations schedule of the Andover ground station are presented.

166. Booton, R. C.,
COMMUNICATION SATELLITES, in SPACE COMMUNICATIONS, New York, McGraw-Hill Book Company, Incorporated, pp. 321-332, A64-11245.

This is a general consideration of the principal characteristics of the communications subsystem of a communications satellite.

Included in the discussion are considerations of: active and passive satellites; satellite orbits; frequency selection; modulation and demodulation; ground-station equipment; spacecraft antenna gain; spacecraft receivers and transmitters; and attitude control.

167. Brown, Harold,
DOD SPACE PROGRAMS, Astronautics and Aeronautics, Vol. 2, pp. 68-71, June 1964, A64-20577.

This is a review of military space activities, present and planned. Instruments in orbit have proved important and practical. It is considered that, from a military viewpoint, the navigational satellite programs will probably be among the first to become operational. Programs to improve communications are discussed. Possible warning and detection systems, and certain concepts of marginal utility are considered. A manned orbital laboratory program has been set up to evaluate man's capability to perform military tasks in space.

168. Cooper, P. T.,
THE ROLE OF THE NATIONAL MISSILE RANGES IN SUPPORT OF SPACE OPERATIONS, Aero/Space Engineering, Vol. 20, pp. 18, 19, and 51-55, September 1961, A61-7777.

This is a historical review of U. S. missile tracking capabilities. The current status of tracking networks, and the management concept which has evolved, are discussed, with attention to the roles of range operator and range user. Maps showing U. S. missile ranges are presented.

169. Fischer, Laurin G.,
MILITARY SATELLITE CONTROL, Astronautics and Aerospace Engineering, Vol. 1, pp. 54-57, September 1963, A63-21540.

This a brief discussion of the requirements and basic elements for facilities control of the planned military communications satellite system of the Defense Communications System (DCS). It is noted that facilities control is necessary because the satellite-communication elements must make a compatible continuous interface with the operating DCS. To be compatible, the satellite facilities control includes a satellite-communications control center, and three of four area control centers. Briefly considered are: (1) station scheduling process, which consists of a mutual assignment of link terminal pairs to an available satellite; (2) tracking systems to determine satellite orbits; and (3) intercommunication of service tracking. A diagram of a generalized model of the tracking and orbital computation subsystem is presented.

170. Fusca, James A.,
SPACE SURVEILLANCE, Space/Aeronautics, Vol. 41, pp. 92-103, June 1964, A65-20258.

This is a discussion of existing and planned satellites for the surveillance of the Earth. The Samos program, consisting of satellites for photographic and electromagnetic reconnaissance, is described, and the possible role that man would play in military reconnaissance from an orbiting satellite is considered. In general, the usefulness of any system for image observation from satellites depends on such factors as resolution, coverage speed, readout speed, analysis speed, and reliability. Orbital perturbations due to the nonspherical shape of the Earth, decay of satellite orbits, and optical considerations of surveillance systems are discussed.

171. Garner, E. T. and Oseas, J.,
THE 4102-S SPACE TRACK PROGRAM, in American Federation of Information Processing Societies, 1964 Fall Joint Computer Conference, Proceedings, Vol. 26, San Francisco, California, October 1964, (A65-14849 05-08), Baltimore, Maryland, Spartan Books, Incorporated, London, England, Cleaver-Hume Press, 1964, pp. 517-526, A65-14860.

This article contains the details of the five functions of the Space Track Sensor Computer (SPASEC) real-time satellite surveillance system. The program locates new satellites soon after launching; keeps up-to-date records of known satellite orbits; provides high-accuracy positional data for use by other systems; provides information on object size, shape, and stability; and indicates orbital change. The associated radar can operate in either the surveillance or tracking mode. Missions are planned based on new information requests, object priority, number of expected sightings, and probability of detection. Changes in an object's status are entered into the computer using simple mnemonic codes and decimal numbers. Identified objects are tracked depending on either priority assignment or data validity tests. All objects to be tracked are compared and the one with the highest track priority is designated. The program directs the radar to the expected target position and continually updates this position until the radar locks on or can no longer acquire the object. If there are no more track requests, the system returns to scan.

172. Glazier, E. V. D., Rechtin, E., and Voge, J. (Editors), AVIONICS RESEARCH: SATELLITES AND PROBLEMS OF LONG RANGE DETECTION AND TRACKING, AGARD Avionics Panel Meeting, Copenhagen, Denmark, 20-25 October 1958, Papers (AGARDograph No. 40.), London, England, New York, Pergamon Press, 1960, 257 pp., A61-1926.

Not abstracted.

173. Harrison, J. E. A. and Chase, R. J., A DATA HANDLING SYSTEM FOR A RADAR INSTALLATION, Appendix I - MAGNETIC TAPE EQUIPMENT FOR A RADAR DATA SYSTEM, by B. H. Weston and N. Whitelam, Appendix II - AN ON-LINE COMPUTING SYSTEM FOR TRACKING RADARS, by R. Spencer-Bamford, Appendix III - MAGNETIC TAPE DECKS FOR A DATA RECORDING SYSTEM, by E. J. Petherick, Society of Instrument Technology, Transactions, Vol. 16, pp. 91-113, September 1964, A64-26082, (Society of Instrument Technology, Meeting, London, England, 24 March 1964).

This is a description of the tracking and data processing facilities at Aberporth, Wales, operated by the Instrumentation and Ranges Department of the Royal Aircraft Establishment. The concepts of accuracy, precision, and granularity of data are discussed as they apply to trajectory-measuring system performance. The requirements of the range were reportedly analyzed and it was decided to obtain two AN/FPS-16 (C-band monopulse) precision tracking radars from the Radio Corporation of America. Data-processing requirements were studied, and British alternatives to the large, expensive, general-purpose U. S. computers were examined. A general description of the on-line data system is presented and is illustrated with block diagrams. Also included is a discussion of system performance and some details on anticipated future developments. Appendix I describes the data-recording system which stores the radar data on magnetic tape. These data reportedly can be applied either directly into a computer or onto punched tape for later analysis on another computer at a distant location. Discussions in Appendix I include: data to be recorded, magnetic tape decks, the recording system and the replay system, the tape-to-card converter, and the physical construction of the system. Diagrams of data flows and timing sequences are included. Appendix II is a description of special-purpose digital/analog computing equipment used for on-line processing. Outputs are reportedly provided in analog form for driving various remote devices, and it is indicated that provision is made for the operation of the computer to be controlled from remote locations. The digital computers, input/output equipment, and the control console are described in some detail and further block diagrams are included. Appendix III contains a more detailed description of the magnetic tape decks that are used. Also presented is a discussion between the authors and seven colleagues well versed on data processing systems.

174. Hoth, D. F., O'Neil, E. F., and Welber, I.,
THE TELSTAR SATELLITE SYSTEM, Bell System Technical Journal, Vol. 42, Pt. 1, pp. 765-799, July 1963, A63-22462.

This is a general description of the Telstar satellite system. The over-all system design is discussed, and the factors affecting the choice of the orbit and of the operating frequencies are considered in some detail. The satellite, the Andover ground station, and the equipment at Cape Canaveral are described, and certain important transmission parameters are presented. Block diagrams are given of the Telstar communications repeater, general transmission plan, ground transmitter, ground receiver, and tracking system.

175. Kaufman, Maxime G.,
POST-DETECTION IN THE NAVY SPACE SURVEILLANCE SYSTEM, IEEE International Convention Record, Vol. 12, Pt. 7, pp. 81-90, 1964, A64-23286. (Institute of Electrical and Electronics Engineers, International Convention, New York, New York, 23-26 March 1964).

This is a discussion of certain aspects of the Navy's satellite detection fence across the southern part of the U. S. Utilising the principle of the radio interferometer, the space surveillance system can locate satellites in space by measuring the direction cosines of the reflected radio energy and triangulating from two or more sites. The direction cosines being determined by measuring phase differences between pairs of antennas, it is important to maintain phase coherency and to minimize all differential phase shifts throughout the post-detection circuits. Characteristics of post-detection filters and phase-measuring circuits are discussed and the effects of incidental phase changes and phase rate are evaluated. Some work on the effect of "phase jump" is also described.

176. Martin, B.,
THE PIONEER IV LUNAR PROBE, in SPACE COMMUNICATIONS, New York, McGraw-Hill Book Company, Incorporated, 1963, pp. 283-297, A64-11243.

This is a description of the design and operation of the communications sytem of the Pioneer IV lunar probe (1959 Nu 1). The system was an FM/PM link consisting of a carrier and three continuous subcarriers whose sideband power accounted for nearly half of the 275-mw output. Phase-coherent techniques were employed for acquiring and automatically tracking the carrier and for demodulating the subcarriers in real time at each tracking site. The payload of the Pioneer IV is briefly described, communications system parameters are tabulated, and sample flight data from the cosmic-ray counter are presented and discussed.

177. Metzger, Sidney,
COMMUNICATIONS-SATELLITES, Astronautics and Aerospace Engineering, Vol. 1, pp. 110-113, November 1963, A64-10163.

This is a review of the state-of-the-art of communication satellites. Recent developments in space tracking techniques and radio command systems are discussed. The objectives of the Mariner experiment are outlined. Recent experiments are briefly reviewed concerning high-precision, long-range tracking and Moon mapping, such as the NASA experiment of precision optical tracking with the S-66 geodetic satellite. Advances in technology made in the flights of Telstar I and II, Relay I, and Syncom I and II are discussed with emphasis on satellite weight reduction, attaining a 24-hour orbit, continuous communication via satellite for a 24-hour period, station keeping, and establishing a man-made orbiting dipole belt.

178. Mueller, G. E. and Spangler, E. R.,
COMMUNICATION SATELLITES, New York, John Wiley and Sons, Incorporated, 1964, 280 pp., A64-25485.

A general review is made of the available technology for the establishment of communication satellite systems. The technical feasibility is granted and is found to rest on eight factors: (1) rocket vehicle hardware and techniques which have been developed largely in the ballistic missile programs; (2) the improvement of performance and reliability through advanced rocket-development programs; (3) the experience in building, launching, and communicating with satellites in space; (4) a gradually improving knowledge of the space environment and its effects on equipment; (5) electric power supplies which derive their energy either from the Sun or from nuclear or chemical fuels; (6) very low-noise receivers; (7) techniques for sensing and controlling vehicle attitude in space; and (8) the ground tracking equipment and high-speed computers needed for accurate ephemeris determination and control. Topics covered include active versus passive satellites, orbit coverage and control, structure and temperature control, choice of frequency, telemetry, tracking and command, reliability, and costs.

179. Murray, B. C.,
THE ARTIFICIAL EARTH SATELLITE - A NEW GEODETIC TOOL, ARS, Semi-Annual Meeting, Los Angeles, California, Preprint 1221-60, 24 pp., 9-12 May 1960, A61-4741.

This describes an inexpensive, yet highly accurate satellite positioning system, appropriate for geodetic applications. In this system, the observations would primarily be made by radar ranging. The proposed satellite would carry an accurate transponder for use with existing high-performance radars, as well as a flashing strobe light, designed to be used in conjunction with existing Baker-Nunn and ballistic cameras to provide an independent check of the range measurements.

180. Pardoe, G. K. C.,
A DESIGN STUDY FOR AN EQUATORIAL, CIRCULAR-ORBIT, COMSAT SYSTEM (BSDC), in Telecommunication Satellites, 13th International Astronautical Federation Congress, Varna, Bulgaria, September 1962, London, England, Iliffe Books, Ltd.; Englewood Cliffs, New Jersey, Prentice-Hall, Incorporated, 1964, pp. 283-317, A64-24583.

This is a description of investigations of the entire problem of communications satellites, performed by the British Space Development Company since 1961, with a view to providing full global service, with emphasis on British Commonwealth and European interests. The subjects treated are Commonwealth and European requirements, system and performance standards, launch vehicle and launching site, factors affecting choice of orbit, equatorial systems, world trunk route, orbit height, the North Atlantic route, summary of satellite network, system mechanics, analysis of traffic and satellite loading, and satellite requirement. Other subjects considered are modulation and telecommunications system, general criteria of telecommunications performance, characteristics of telecommunications design, coexistence of the system with current microwave services, ground station aerials, ground stations and facilities, master — technical control center, zone control stations, factors affecting satellite design, satellite configuration, and control system. The discussion includes solar-cell array, telecommunications repeaters, system costs and revenue, and expansion of system with synchronous system.

181. Peterson, A. M., Leadebrand, R. L., Jaye, W. E., Dyce, R. B., Dolphin, L. T., Presnell, R. I., Rorden, L. H., and Schlobohm, J. G.,
RADAR ECHOES OBTAINED FROM EARTH SATELLITES 1957 ALPHA AND 1957 BETA, in Avionics Research: Satellites and Problems of Long Range Detection and Tracking, AGARD Avionics Panel Meeting, Copenhagen, Denmark, 20-25 October 1958, Papers (AGARDograph No. 40), London, England, New York, Pergamon Press, 1960, pp. 140-155, A61-2012.

Not abstracted.

182. Posner, Edward C.,
OPTIMAL SEARCH PROCEDURES, IEEE Transactions on Information Theory, Vol. IT-9, pp. 157-160, July 1963, Contract No. NAS 7-100, A63-23413.

This is a consideration of a restricted class of search procedures for a satellite lost in a region of the sky. The satellite must be found by a radar search. The procedures under consideration allow the use of a preliminary search, which may be done with a wider beam than is required for the final search. The purpose of the preliminary search is to obtain a ranking of the various portions of the sky, so that the final search can examine the more likely regions of the sky first. It is shown that a preliminary search can reduce the expected search time, with no matter how wide a beam it is carried out. It is also shown that the preliminary search with the narrowest possible beam is best.

183. Radio Corporation of America, Moorestown, New Jersey,
TRADEX INSTRUMENTATION RADAR, by John Hagefstration and Russell Newell, February 1963, Contract No. DA 36-034-ORD-3063, AD-414 117.

This report summarizes the overall Tradex Instrumentation Radar program and outlines the system design philosophy concepts.

Success in fulfilling these concepts is reflected in descriptions of Tradex radar techniques, system operation and radar subsystems. Data, obtained during the system checkout program by the Tradex radar tracking ICBM satellites, and the Moon, is presented and analyzed. The system checkout tests provide preliminary indications of radar performance parameters such as tracking accuracy and precision, and range and Doppler resolution. Additional data and analysis will be required in the future to render completely definitive parameters. However, these tracking tests performed demonstrated the high capability of the Tradex radar to acquire and skin track small cross-section targets at long ranges, and to obtain parametric and phenomenological information on all targets in the radar beam at both UHF and L-band frequencies.

184. Royal Aircraft Establishment, Farnborough, England,
THE ORBITAL ELEMENTS OF ARIEL 1 FOR APRIL-AUGUST 1962 AND A COMPARISON OF RAE AND NASA EPHEMERIDES, by R. H. Merson and R. J. Tyler, July 1963, Report No. RAE-Technical Note No. Space 39, AD-417 705.

The RAE orbit improvement program has been used to determine the orbital elements of the ARIEL 1 satellite (1962) for the periods 28 April - 6 July 1962 and 4-19 August 1962, from minitrack observations provided by NASA. Using these elements, two sample ephemerides each extending over one orbital period have been obtained with the RAE ephemeris program. These are compared with the corresponding NASA ephemerides.

185. Siry, J. W.,
SATELLITE AND PROBE ORBIT DETERMINATION: PAST, PRESENT, AND FUTURE, in Space Trajectories, American Astronautical Society, The Advanced Research Projects Agency, and Radiation Incorporated Symposium, Orlando, Florida, 14 and 15 December 1959, New York, Academic Press, 1960, pp. 9-13, A61-2034.

Not abstracted.

186. Walker, John M.,
RESEARCH REQUIREMENTS FOR FUTURE MANNED SPACE FLIGHT COMMUNICATIONS, in 2nd Manned Space Flight Meeting, New York, American Institute of Aeronautics and Astronautics, pp. 17-22, 1963, A63-18984.

This is a discussion of communications research activities required for future manned space flight missions, emphasizing research geared towards increasing the information received by spacecraft. Methods for improving the performance of the communications system are considered, including increasing the antenna sizes, and using Lasers. Described is the S-66 Laser tracking experiment which is to be an initial step in providing many of the basic facts needed before optical technology may be brought to bear on the problems of space communications and tracking. Outlined are research approaches to minimizing the blackout period created by the shock-induced plasma surrounding the spacecraft, as are the possibilities of advances in component technology to increase the reliability of the communications systems on spacecraft and to reduce their size, weight, and complexity. The major constraints imposed on previous work that are not applicable to manned space flight are delineated.

187. Williams, Donald D. and Cole, Roger W.,
SYNCOM, in TELECOMMUNICATION SATELLITES, London, England, Iliffe Books, Ltd.; Englewood Cliffs, New Jersey, Prentice-Hall, Incorporated, 1964, pp. 130-155, A64-24578.

This is a description of the first series of Syncom satellites. The topics considered include synchronous orbit, transfer orbit, effects of errors on the orbit, perturbations of a synchronous orbit, control-system objectives, operation of the control system, attitude sensing, and Syncom 1 (1963 4A) and 2 (1963 31A). It is stated that future plans are proposed for an advanced synchronous communications satellite which will have an 8:1 increase in volume and mass over the present Syncom type of satellite.

Section IV. EQUIPMENT AND FACILITIES FOR ORBIT DETERMINATION, EARTH-BASED

This section includes tracking station locations and number of stations; type of tracking stations; tracking methods; analysis of multistation tracking methods; optical trackers, techniques, and accuracies; electronic trackers, techniques, and accuracies; methods such as radiointerferential tracking, choosing optimum locations for tracking stations, linear combination of ranges and range rates, Doppler tracking, radar tracking, etc.; data recording techniques; trajectory monitor (real-time orbit determination); capabilities and performance; and Laser and injection-Laser considerations for tracking.

188. Aardoom, L. and De Munck, J. C., AN EXPERIMENT ON PHOTOGRAPHIC SATELLITE TRACKING, in The Use of Artificial Satellites for Geodesy; Proceedings of the 1st International Symposium on the Use of Artificial Satellites for Geodesy, Washington, D. C., 26-28 April 1962, Committee on Space Research (COSPAR), International Union of Geodesy and Geophysics, and UNESCO, Amsterdam, Holland, North-Holland Publishing Company, New York, Interscience Publishers Division, John Wiley and Sons, Incorporated, 1963, pp. 158-160, A63-24719.

This is a brief description of experimental photography of satellites using an equatorially mounted camera of 12-centimeter focal length and 21-centimeter aperture. An accuracy of ± 2 inches in position and 1-2 milliseconds in time is expected for satellites brighter than sixth magnitude.

189. Advanced Research Projects Agency, Washington, D. C., Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, SYNCHRONIZATION OF TRACKING ANTENNAS, by R. E. A. Putnam, September 1959, Report No. ARPA-TN-1278SFS-6, AD-402 139.

This report presents synchronization of tracking antennas for satellite detection.

190. Aerospace Corporation, Los Angeles, California, A SYSTEMATIC APPROACH TO THE CHOICE OF STATION LOCATIONS FOR LOW-ALTITUDE SATELLITE TRACKING IN NEAR EQUATORIAL ORBITS, by G. J. Bonelle, March 1964, Report No. SSD-TDR-64-27, Contract No. AF 04(695)-269, AD-433 753.

This report is primarily concerned with methods of choosing optimum locations for tracking stations, which provide maximum support for satellites with near equatorial orbits. The method chosen makes use of the considerations that (1) the orbits ground traces are concentrated in the vicinity of the latitude equal to the maximum inclination of the orbit and (2) most of the direct launchings possible from Cape Kennedy will have a very limited range of orbit inclinations; i.e., from 28 ½ degrees to 34 ½ degrees. The relative merits of the sites being considered using the above method are then tested using the following criteria: (1) that maximum number of tracking passes per day be supported, (2) that a minimum number of gaps exist in network coverage, (3) that stations provide early orbit support, and (4) that maximum support be given for recovery phases of satellite missions. Using the above method it is possible to select stations locations for a completely new network or to select a station or stations to provide greater support.

191. Air Proving Ground Center, Eglin Air Force Base, Florida, MANNED SPACE FLIGHT NETWORK STATION 17, EGLIN AFB, SUPPORT FOR THE SATURN, SA-5, MISSION, by Ronald L. Decosmo and Richard E. Williamson, August 1964, Report No. APGC-TDR-64-57-0185W1, AD-447 891.

This report describes the Station 17 support for the fifth mission in the NASA directed Saturn I development program from 29 January until 1 April 1964. The general mission objectives, actual mission profiles, support facilities, and skin tracking results are presented in this report. Special emphasis is placed on the skin tracking and acquisition-techniques developed by Station 17, Eglin Air Force Base, Florida.

192. Anders, J. V., Higgins, E. F., Jr., Murray, J. L., and Schaefer, F. J., Jr., THE PRECISION TRACKER, Bell System Technical Journal, Vol. 42, Pt. 2, pp. 1309-1356, July 1963, A63-22479.

This is a description of the precision tracker employed at the Andover, Maine and Pleumeur-Bodou, France, stations to find the Telstar satellite (1962 Alpha Epsilon 1) and direct the horn-reflecter antennas when required, and, at regular intervals during subsequent passes, to provide the precise tracking data required for prediction of future orbital parameters. The tracker is a simultaneous-lobing, amplitude-comparison, passive, CW tracker based in principle and design upon a monopulse tracking radar. The subsystems are described in detail and block diagrammed. These subsystems include: (1) the antenna, RF processing, and preamplifiers; (2) tracking receiver; (3) antenna-positioning system; (4) acquisition receiver; (5) frequency standard and test signal; and (6) control console.

193. Author Unknown,
COSPAR WORLD LIST OF SATELLITE TRACKING STATIONS. II-RADIO STATIONS, COSPAR Information Bulletin, No. 18, 55 pp., April 1964, A64-20349.

This is a listing of satellite and space-probe tracking stations prepared by World Data Centre C and Radio Research Station, Slough, England, in cooperation with the Space Research Management Unit, Office of the Minister of Science, UK, in accordance with Resolution 6 of the Fourth COSPAR Meeting in Florence, April 1961. The list has been prepared from compilations submitted by the adhering national institutions or the national correspondents for radio tracking of 10 countries. The list is arranged geographically, the stations being grouped under the country in which they are situated.

194. Author Unknown,
FRENCH PROGRAM FOR THE ESTABLISHMENT OF GROUND STATIONS (LE PROGRAMME FRANCAIS D'ESTABLISSEMENT DE STATIONS AU SOL), Air et Cosmos, pp. 15, 30 September 1963, A63-24426 (In French).

This is a brief description of the proposed French network of stations for satellite tracking, telecontrol and the reception of remote measurements, which will be linked to the American network, and will comprise four stations to be located approximately on a meridian between latitudes 30°N and 30°S. The system will begin to operate in early 1965. Briefly described is the equipment to be used, including the synchronizing devices, a device for interferometric localization, and the equipment for teletype linking.

195. Author Unknown,
GROUND STATIONS FOR COMMUNICATIONS SATELLITES, Interavia, Vol. 18, pp. 1727-1731, November 1963, A64-11594.

This is a review of the needs and characteristics of proposed and operating ground stations for communications satellite networks. Both stationary and transportable stations are considered, including the ITT station at Andover and the transportable station at Lakehurst which is currently in use for Syncom experiments and will later be used for military communications satellites. A table of 29 operational and near-operational ground stations, and a map indicating their locations throughout the world, are included.

196. Author Unknown,
TRACKING STATIONS OF THE NATIONAL CENTER OF SPACE STUDIES (STATIONS DE POURSUITE DU CENTRE NATIONAL D'ETUDES SPATIALES), COSPAR, 7th Meeting, and 5th International Space Science Symposium, Florence, Italy, Paper, 22 p., 8-20 May 1964, A64-18828 (In French).

This is a general description of the role, logic operation, principles, and primary equipment of the tracking stations of the French space study center. The description includes also subassemblies, feeders, converting pre-amplifiers, receivers, detectors, gain switch and automatic control, filters, phasemeter, analog recorder, measurement of the frequency received, drive and controlling devices, multiplexer, coder, and digital recorder. A tabulation of the technical characteristics of the equipment is provided.

197. Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland,
THE DOPLOC DARK SATELLITE TRACKING SYSTEM, by A. L. G. Ebey and V. W. Richard, March 1963, Report No. BRL-TN-No. 1195, AD-403 879.

The DOPLOC DARK Satellite Tracking system is described and tracking results are presented. DOPLOC is a radio reflection Doppler tracking system deriving its name from the Doppler frequency phase-locked tracking filter technique used. DARK, i. e. non-radiating, satellites are illuminated by a ground-based transmitter. The signals reflected from illuminated satellites are received at one or more ground-based receiving sites. A method has been developed for the determination of a complete set of orbital parameters from Doppler data recorded in the course of a single pass of a satellite. Numerous orbital solutions have been obtained with Doppler data from a single receiver recorded during a single pass of a satellite. Computing times of 2 to 4 minutes are required with the BRLESC computer. The DOPLOC tracking method has general application to the tracking of projectiles, rockets, guided missiles, and space vehicles.

198. Brown, D., Associates, Incorporated, Eau Gallie, Florida, INVESTIGATION OF THE FEASIBILITY OF SELF-CALIBRATION OF TRACKING SYSTEMS, by Duane C. Brown, Norman Bush, and Jerome L. Sibol, May 1964, Report No. AFCRL-64-441, Contract No. AF 19(628)-3286, AD-602 799.

The error model best estimate of trajectory (EMBET) is derived for a tracking system measuring any linear combination of ranges and range rates. Provisions are made for the introduction of any functional statistical constraints on the coefficients of the error model. Provisions are also made for the introduction of dynamic constraints expressed either in terms of explicit functions or in terms of general differential equations of motion. A rigorous extension of EMBET to apply to a hierarchy of orbits (rather than individual trajectory points) is developed. It provides an altogether practical solution to the long standing problem of the simultaneous adjustment of all observations made by all sensors on an unlimited number of orbits or epochal intervals. This extension, called NEO-EMBET (N-epoch orbital EMBET), also calibrates both stable and unstable components of the error models of all observational channels while simultaneously estimating the orbital parameters at all specified epochs as well as any gravitational and drag parameters considered to be unknown.

199. Budinov, I. Ia., TRANSISTORIZED THREE-STAGE PHOTOELECTRIC TRACKING SYSTEM (TREKHSTUPENCHATAIA FOTOELEKTRICHESKAIA SLEDIASHCHAIA SISTEMA NA TRANZISTORAKH), Iskusstvennye Sputniki Zemli, No. 14, pp. 74-80, 1962, A63-18647 (In Russian).

This is a discussion of a balloon-borne tracking system designed to focus continuously onto the Sun the various packaged instruments used to study direct solar radiation in a free atmosphere. The design, structural details, and principles of operation of the system are described and partially illustrated. A block diagram of the system and diagrams of its electric circuit and mismatch-signal transmitter are presented. The characteristics of the tracker are outlined.

200. Cook, J. S. and Lowell, R., THE AUTOTRACK SYSTEM, Bell System Technical Journal, Vol. 42, Pt. 2, pp. 1283-1307, July 1963, A63-22478.

This is a description of the operation and design characteristics of the autotrack system, which accurately senses the direction of

arrival, at the horn-reflector antenna, of the microwave beacon signal from the Telstar satellite (1962 Alpha Epsilon 1). When this direction does not coincide with the horn-reflector pointing direction, error-correcting voltages are automatically generated to enable the antenna-direction system to steer the antenna toward the satellite. A simple analysis of error voltage generation is presented, and the system performance is described. Measurements at Andover, Maine, have shown that an angular pointing error of less than 0.005 degree is maintained by the antenna when using the autotrack system to follow the satellite.

201. Cooper, B. and McClure, R.,
SPACE-RESEARCH GROUND STATION, Electrical Communication, Vol. 39, No. 1, pp. 25-36, 1964, A64-19899.

This is a description of the experimental ground station for satellite communication developed at the ITT Federal Laboratories in Nutley, New Jersey, and completed in 1960. This fixed station was used for design studies toward the development of an air-transportable, medium-capacity, space-communication terminal. Tables are given for the station performance with active and passive satellites and the performance of the communication-receiver and antenna-tracking systems in the Telstar and Relay satellite programs and in experiments using the Moon as a passive reflector.

202. Cornell Aeronautical Laboratory, Incorporated, Buffalo, New York,
HIGH POWER PROGRAM HIGH POWER PROJECT-PROJECT DELILAH, by L. J. Anderson and L. H. Groth, December 1963, Contract No. DA 30-069-ORD-2554, AD-427 765.

This report contains: radar observations of satellites, satellite acquisition and tracking, Doppler programmer, experimental results, S-band auroral clutter, correction of antenna reflector surface, and resonant ring development (high power resonant ring and intermediate power resonant ring).

203. Crooks, J. W., Jr.,
A SIMPLIFIED HIGH PRECISION 200 MILLION MILE TRACKING, GUIDANCE AND COMMUNICATION SYSTEM, Planetary and Space Sciences, Vol. 7, pp. 94-107, July 1961, A62-2052, (AFBMD/STL 4th Symposium on Advances in Ballistic Missile and Space Technology, Los Angeles, California, 24-27 August 1959).

This is a description of a long-range tracking system based on the Azusa techniques. A special feedback technique is used which employs the same klystron for transmitting as well as for the local oscillator in the transponder. In order to provide very sensitive measurement of range rate, a coherent carrier modification was added to the Azusa ground stations and to most Azusa transponders in current use. The modification involves phase-locking the microwave klystron oscillator in the transponder to a received reference frequency.

204. Dietrich, Ernst,
PARTICIPATION OF THE GERMAN FEDERAL POST OFFICE DEPARTMENT IN THE EXPERIMENTAL COMMUNICATION TRANSMISSIONS BY ARTIFICIAL EARTH SATELLITE (BETEILIGUNG DER DEUTSCHEN BUNDESPOST AN DEN VERSUCHEN ZUR NACHRICHTENUBERTRAGUNG MIT HILFE KÜNSTLICHER ERDSATELLITEN), Deutsche Gesellschaft für Rakententechnik und Raumfahrt, 3rd European Space Flight Symposium, Stuttgart, Germany, Paper 1540 (62), 4 pp., 21-24 May 1963, A63-19630 (In German).

This is a discussion of a German ground station for satellite communications, under construction in Raisting near Weilheim. A narrow-band installation employing a 9-m-diam. parabolic reflector, with a capacity of 12-telephone channels, is to be completed in 1963. More distant (summer 1964), is the completion of a wideband installation employing a 25-m-diam. parabolic reflector, with a capacity of several hundred telephone channels and a TV capability. Its input will be supplied by a liquid-helium cooled maser. The 6-Gc transmitter will have an output power of 2 kilowatts. Weather protection of the antenna will be achieved by the use of a spherical inflatable 49-m-diam. radome. Satellite tracking by the antenna will be based on a computer-controlled automatic precision tracking system.

205. Drucker, J. E.,
TRANSPORTABLE-STATION OPERATION WITH TELSTAR AND RELAY SATELLITES, Electrical Communication, Vol. 39, No. 1, pp. 113-122, 1964, A64-19907.

This is a discussion of technical parameters and operational experience with the transportable space-communication terminal developed and constructed by the ITT Federal Laboratories, Nutley, New Jersey. Tests show that the primary causes of variation in signal level are the range and spin modulation of the satellite.

Tracking errors are said to lie within ± 0.03 degree and pointing errors within ± 0.3 degree, even in winds as high as 58 miles per hour.

206. Fricke, C. L. and Watkins, C. W. L.,
ANALYSIS OF A FOUR-STATION DOPPLER TRACKING METHOD USING A SIMPLE CW BEACON. Appendix A - EXISTENCE OF INFINITE ERRORS. Appendix B - TRIANGLE RULE OF INFINITE ERROR. Appendix C - INFINITE ERRORS IN A RECTANGULAR CONFIGURATION. Appendix D - STATION-LOCATION ERRORS. Appendix E - DETERMINATION OF VELOCITY. Appendix F - ERRORS IN VELOCITY, U. S. NASA TN D-748, 38 pp., April 1961, A61-4743.

This is a presentation of a Doppler tracking method using a small simple CW beacon transmitter in conjunction with four Doppler receiving stations to determine position and velocity of a space research vehicle. The exact transmitter frequency need not be known, but an initial position is required, and it is necessary that Doppler frequencies be measured with extreme accuracy. The errors of the system are analyzed and general formulas derived for position and velocity errors. The proper location of the receiving stations is discussed. A rule for avoiding infinite errors, and error charts for ideal station configurations, are included.

207. Götze, S.,
ZUR MESSWERT-REGISTRIERUNG AUS FLUGKÖRPERN, Raketentechnik und Raumfahrtforschung, Vol. 5, pp. 26-29, January-March 1961, A61-4734 (In German).

This is a discussion of the development in data recording techniques, considering their application in the recording of data received from space vehicles. Techniques and systems in ground control stations are studied, and the possibility of data recording directly in the space vehicle is explored.

208. Henriksen, S. W.,
ELECTRONIC TRACKING OF ARTIFICIAL SATELLITES, in The Use of Artificial Satellites for Geodesy, Proceedings of the 1st International Symposium on the Use of Artificial Satellites for Geodesy, Washington, D. C., 26-28 April 1962, Committee on Space Research (COSPAR), International Union of Geodesy and Geophysics, and UNESCO, Amsterdam, Holland, North-Holland Publishing Company, New York, Interscience Publishers Division, John Wiley and Sons, Incorporated, 1963, pp. 194-198, A63-24723.

This is a brief review of the different electronic tracking devices used for artificial satellites. Both interferometer and radar tracking systems are discussed, emphasizing the advantages of HF techniques.

209. Hewitt, J.,
A 24-INCH F1 FIELD FLATTENED SCHMIDT CAMERA FOR SATELLITE TRACKING, COSPAR, 4th International Space Science Symposium, Warsaw, Poland, Paper, 3 pp., 3-11 June 1963, A63-18962.

This is a description of a 24-inch tracking camera which will record satellites of magnitude + 9. The position of satellites can be measured with a precision of 2 inches of arc and 0.001 second or better in time. The optical system, sector shutter, capping shutter, and timing system are described, and the performance is discussed.

210. Instruments Corporation of Florida, Incorpoated, Melbourne, Florida,
STUDY OF THE FEASIBILITY OF ROCKET AND SATELLITE APPROACHES TO THE CALIBRATION OF TRACKING SYSTEMS, by Duane C. Brown, Norman Bush, and Jerome L. Sibol, October 1963, Report No. AFCRL-63-789, Contract No. AF 19(604)-8493, AD-425 480.

The problem of calibration of tracking systems is reviewed at length and a specific approach to calibration is defined. Self-calibration is held forth as the logical primary goal of a program of calibration. The prerequisites to self-calibration are established and specific means for testing the concept are proposed. Results of extensive numerical simulations of postulated rocket and satellite programs of calibration of Mistram, Glotrac, and C-band radars are reported. Special consideration is given to problems of geodetic survey. Relative costs of satellite and rocket programs of calibration are feasible, if properly designed, but a satellite program would yield appreciably superior results at far less cost than a rocket program of comparable effectiveness. A rocket program would be of value primarily as a supplement to a satellite program.

211. Jacobson, Robert I.,
THE ARIS INSTRUMENTATION RADAR, in 7th National Convention on Military Electronics, Washington, D. C., Proceedings, 9-11 September1963, Conference sponsored by the Professional Technical Group on Military Electronics, Institute of Electrical and Electronics Engineers, New York, Institute of Electrical and Electronics Engineers, 1963, pp. 60-63, A64-22487.

This is a description of the ARIS (integrated instrumentation radar), a major subsystem of the first two Atlantic range instrumentation ships for the U. S. Air Force. The device uses a number of modern radar techniques to make accurate position and multifrequency target amplitude measurements on multiple high-speed targets located within its pencil beam. Both beacon and skin tracking are available. All data outputs are available in digital form for use in the instrumentation system digital computer. The first ship was delivered fully checked out, integrated, and ready for evaluation in April 1963, 21 months after the date of contract signing for ship conversion and instrumentation development, manufacture, installation, and checkout.

212. Janeff, W.,
SATELLITE-TRACKING RECEIVER, Electrical Communication, Vol. 39, No. 1, pp. 98-112, 1964, A64-19906.

This is a description of the satellite-tracking receiver of the transportable space-communication terminal developed and constructed by the ITT Federal Laboratories, Nutley, New Jersey. The major portion of the paper is devoted to a discussion of error sources, pointing accuracy, and tests proving the effectiveness of the design.

213. Johnson, C. M.,
INJECTION-LASER SYSTEMS FOR COMMUNICATIONS AND TRACKING, Electronics, Vol. 36, pp. 34-39, 13 December 1963, A64-11737.

This is a discussion of some possible applications of semiconductor injection Lasers for communications and precision target tracking systems. Considered are theoretical aspects of Laser communications, available bandwidths, usable signals, the characteristics of a pulse system, available transmitter power, and efficiency. An experimental injection Laser system is briefly described, as well as a hypothetical 5-Mc bandwidth link between a satellite and a ground station, in order to illustrate the requirements placed on a GaAs Laser in an operational system. The characteristics of GaAs Lasers are discussed, along with considerations associated with Laser tracking. As an example, the problem of one space vehicle tracking another at 50 miles is briefly examined.

214. Kirch, James E.,
THE GODDARD RANGE AND RANGE RATE SYSTEM FOR SATELLITE TRACKING, in 10th Annual East Coast Conference on Aerospace and Navigational Electronics, Baltimore, Maryland, 21-23 October 1963, Proceedings, Conference sponsored by the Baltimore Section of the Institute of Electrical and Electronics Engineers and Professional Technical Group on Aerospace and Navigational Electronics, North Hollywood, Western Periodicals Company, 1963, pp. 2.3.4-1 to 2.3.4-5, A64-18291.

This is a description of the Goddard Range and Range Rate System, developed for the Goddard Space Flight Center to produce accurate data for use in orbital computations. The system is said to be simple in concept, uncomplicated in operation, and dependable in performance.

215. Krylov, G. N., Martynenko, I. A., Pogrebniak, E. B., and Sergeera, M. K.,
AN AUTONOMOUS OPTICAL METHOD FOR THE DETERMINATION OF THE ORIENTATION OF AN EARTH SATELLITE IN SPACE (AVTONOMNYI OPTICHESKII METOD OPREDELENIA ORIENTATSII SPUTNIKA ZEMLI V PROSTRANSVE), Iskusstvennye Sputniki Zemli, No. 14, pp. 145-153, 1962, A63-18654 (In Russian).

This is a presentation of a method of satellite orientation, based on the determination of the position of the Sun within the satellite system of coordinates. Use is made of solar-radiation sensors, the recordings of which are proportional to the cosine of the angle formed by the sensor axis and the direction to the Sun. A flexible system of coordinates connected with the Earth is introduced, and the transfer matrix from this system to the satellite system of coordinates is determined from the sensor recordings. An additional relation between the two coordinate systems is obtained by means of scanning sensors, and is used to determine the angle of rotation about the axis of the system satellite/Sun.

216. Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts,
CROSS-SECTION MEASUREMENTS OF THE ECHO II SATELLITE BY THE MILLSTONE L-BAND RADAR, by R. F. Julian and D. P. Hynek, April 1964, Report No. ESD-TDR-64-43, Contract No. AF 19(628)-500, AD-602 751.

The report is a summary of the Millstone radar tracking activities during the early revolutions of ECHO II. Eight revolutions were tracked and cross-section measurements were taken during the satellite's first four days in orbit, followed by four additional tracks during the next three weeks. All cross-section measurements beginning with revolution 4, the first observable at Millstone, display a fading pattern indicating that the balloon had not attained full sphericity, or at least contained significant surface irregularities. No essential change in the fading pattern was noted throughout the period that measurements were taken, except for perhaps more frequent fading during the later passes. Starting with revolution 5, the first complete horizon-to-horizon measurement made, a periodicity of approximately 104 seconds was observed. This periodicity was also apparent during the later passes. The estimated average radar cross section during these observations was about one-half-the theoretical 1330 square meters. A pulse-to-pulse cross section versus time record is included for revolutions 5 and 321.

217. Lockwood, G. E. K.,
SPIN RATE OF THE SATELLITE ECHO I AS DETERMINED BY A TRACKING RADAR, Canadian Journal of Physics, Vol. 38, p. 1713, December 1960, A61-1313.

This is an analysis of the radar signals reflected from the satellite for each of the nine passes observed. The radar signal is detected in two orthogonal channels, right and left circular polarization. Transmitted polarization is left circular, but the main component of the received signal has right circular polarization. A regular fast scintillation in the received signal has been observed in all passes tracked. Determination of the satellite's spin rate is possible by studying the scintillations of the received signal and taking the fabrication method of the balloon into account. The assumption is developed that the scintillations are caused by the motion of the (82) gores of which the balloon is made up, and that there is a one-to-one correspondence between each observed fade and the opposition of a gore. The scintillation rates of 134 fades per minute (for the first eight observations) and of 154 fades per minute (for the last observation) correspond to periods of rotation of 36.8 seconds and 31.9 seconds, respectively. The data accounting for the spin-rate increase observed are interpreted.

218. Marshall, A. C. and Houston, R. E.,
INSTRUMENTATION FOR THE AUTOMATIC DOPPLER TRACKING OF EARTH SATELLITE RADIO SIGNALS, New Hampshire, University, Science Rep. 1 (AFCRL 1054), 42 pp., July 1961, A63-3069.

This is a description of instrumentation for the acquisition of a satellite radio transmission and the automatic tracking of its Doppler frequency shift. Techniques for the operation of the individual components, as well as for the over-all operation of the entire system, are listed. A few records obtained from actual satellite observations are shown. The usefulness of this type of instrumentation is explored.

219. Mason, J. F. and Wolff, M. F.,
MISSILE AND SPACE ELECTRONICS - EARTH-BASED ELECTRONICS, Electronics, Vol. 34, pp. 108-118, 17 November 1961, A62-978.

This is a discussion of the current status of, and research and development in, the following areas: (1) missile-range electronic instrumentation, (2) satellite and space-probe tracking and data-acquisition networks, (3) methods for the detection of enemy missiles and space vehicles, and (4) radar and radio astronomy.

220. Massevitch, A. G.,
OPTICAL OBSERVATION TECHNIQUES, in The Use of Artificial Satellites for Geodesy; Proceedings of the 1st International Symposium on the Use of Artificial Satellites for Geodesy, Washington, D. C., 26-28 April 1962, Committee on Space Research (COSPAR), International Union of Geodesy and Geophysics, and UNESCO, Amsterdam, Holland, North-Holland Publishing Company, New York, Interscience Publishers Division, John Wiley and Sons, Incorporated, 1963, pp. 123-140, A63-247[illegible]6.

This is a discussion of the current state-of-the-art of satellite tracking, emphasizing optical observational techniques. Photographic tracking procedures and the precise determination of coordinates and of time are covered. The use of long-focal telescopes is described.

221. McDonald, W. S.,
SATELLITE TRACKING FROM SEVERAL COORDINATED DOPPLER RECEIVING STATIONS, in Avionics Research: Satellites and Problems of Long Range Detection and Tracking, AGARD Avionics Panel Meeting, Copenhagen, Denmark, 20-25 October 1958, Papers (AGARDograph No. 40), London, England, New York, Pergamon Press, 1960, pp. 174-187, A65-2006.

Not abstracted.

222. Miczaika, G. R. and Dieter, N. H.,
A FAST TECHNIQUE FOR SATELLITE POSITION DETERMINATION WITH LARGE TRACKING CAMERAS, Planetary and Space Science, Vol. 7, pp. 76-80, July 1961, A62-2057, (4th AFBMD/STL Symposium on Advances in Ballistic Missile and Space Technology, Los Angeles, California, 24-27 August 1959).

This is a description of a special "blink microscope" for the detection of satellite images to be photographed by large tracking cameras. The system has provisions for determining satellite positions in an astronomical coordinate system by means of a third optical channel into which the properly selected portion of a star atlas can be inserted and compared.

223. Mitre Corporation, Bedford, Massachusetts,
SATELLITE INTERCEPTION CAPABILITY OF BMEWS, by V. A. Didio, September 1963, Report No. W6L32 and ESD-TDR-63-452, Contract No. AF 19(628)-2390, AD-419 184.

A graphical illustration of the satellites interception capability of the three-site ballistic missile early warning system (BMEWS) is presented. The interception capability of the system is determined by considering only the geometrical region illuminated by the radars, neglecting probability of detection or target characteristics. Satellite coverage provided by each site is shown in terms of the heights and inclination angles of orbits which will intersect the coverage. The probability of penetration within 12 hours of launch and on the first orbit is tabulated in terms of these parameters.

224. Molz, K. F.,
THE AN/FPS-85 SATELLITE TRACKING PHASED ARRAY RADAR, IEEE Transactions on Aerospace, Vol. AS-2, pp. 135-138, April 1964, A64-18091, (International Conference and Exhibit on Aerospace Electro-Technology, Phoenix, Arizona, 20-23 April 1964).

This is a presentation of techniques and equipment used in connection with the AN/FPS-85 radar system which is part of the overall USAF Space Detection and Tracking system. This radar is a phased array system incorporating many advanced techniques. It is completely computer-controlled to take advantage of the inertialess scanning beams of the phased array. Illustrations of the installations and hardware are included. The features of the system are: long range detection capability, high transmitted power, inertialess electronic beam steering, multiple receiving beam capability, high reliability, extreme flexibility, and determination of target trajectories and orbits and maintenance of ephemerides on large numbers of satellites.

225. Muller, Paul and Barlier, F.,
DISCUSSION OF PHOTOGRAPHIC POSITIONS OF SATELLITES OBTAINED BY A SHORT FOCAL-LENGTH CAMERA (DISCUSSION DES POSITIONS PHOTOGRAPHIQUES DE SATELLITES OBTENUES AVEC UNE CHAMBRE A COURT FOYER), in The Use of Artificial Satellites for Geodesy, Proceedings of the 1st International Symposium on the Use of Artificial Satellites for Geodesy, Washington, D. C., 26-28 April, 1962, Committee on Space Research (COSPAR), International Union of Geodesy and Geophysics, and UNESCO, Amsterdam, Holland, North-Holland Publishing Company; New York, Interscience Publishers Division, John Wiley and Sons, Incorporated, 1963, pp. 161 and 162, A63-24720 (In French, with summaries in English and Russian).

This is a brief error analysis of the reduction of photographic plates obtained with a K-37 camera. It is indicated that an accuracy of ± 4 inches for the position of a satellite can be obtained.

226. Newhall, Nicholas S.,
JPTRAJ-THE NEW JPL TRAJECTORY MONITOR, in American Federation of Information Processing Societies, 1964 Fall Joint Computer Conference, San Francisco, California, October 1964, Proceedings, Volume 26 (A65-14849 05-08), Baltimore, Maryland, Spartan Books, Incorporated; London, England, Cleaver-Hume Press, 1964, pp. 481-488, A65-14857.

This is a description of a system that coordinates the execution and communication between independently written programs - from preliminary conic studies to real-time orbit determination and midcourse maneuver - and provides a flexible modification and checkout scheme. As an illustration of the system's operation, an example is given of the design of a Ranger Earth-Moon

trajectory. However, the monitor is not seen to be limited to spaceflight programs alone; any IBM 7094 system with disk file storage may use it, and modification is underway to permit operation on a direct-couple system, in a language other than the current Fortran II, Version 3.

227. Paetzold, H. K.,
INTERNATIONALE BEOBACHTUNG VON ERDSATELLITEN, Weltraumfahrt, Vol. 12, pp. 81-89, May-June 1961, A61-7780 (In German).

This is a discussion of the scientific importance of a worldwide net of satellite tracking stations in view of the difference in local atmospheric conditions.

228. Pettengill, G. H. and Kraft, L. G., Jr.,
EARTH SATELLITE OBSERVATIONS MADE WITH THE MILLSTONE HILL RADAR, in Avionics Research: Satellites and Problems of Long Range Detection and Tracking, AGARD Avionics Panel Meeting, Copenhagen, Denmark, 20-25 October 1958, Papers (AGARDograph No. 40), London, England, New York, Pergamon Press, 1960, pp. 125-134, A61-2011.

Not abstracted.

229. Philco Corporation, Palo Alto, California,
INTERIM MULTIPLE SATELLITE CONTROL SYSTEM STUDY, VOLUME I, February 1962, Report No. WDL-TR-1767, Contract No. AF 04(647)-829, AD-453 200.

The current satellite control facility (SCF) has evolved over the past few years in response to requirements to support the many different satellite programs included under WS-117L and other programs. As additional requirements have arisen, new tracking and control stations have been added to meet them. The current facility has grown to include many such stations and one central control point. These stations have many common features, but no two stations are alike in detail or in capability. This report attempts to clarify many of the most important interrelationships, thereby focusing attention upon those areas which are most critical to the successful operation of the SCF. On the basis of this new insight, a plan is proposed which is designed to better enable the SCF to support the planned activities during 1963.

230. Plotkin, H. H.,
THE S-66 LASER SATELLITE TRACKING EXPERIMENT, in Quantum Electronics, 3rd International Congress, Proceedings, Paris, France, 11-15 February 1963, Vol. 2, Conference sponsored by the Union Radio Scientifique Internationale (URSI), Federation Nationale des Industries Electroniques, and Office of Naval Research, Paris, France, Dunod Editeur; New York, Columbia University Press, 1964, pp. 1319-1332, A64-23997.

This is a discussion of the optical tracking experiment planned by NASA for the S-66 satellite, which consists of illuminating a special satellite-borne reflector with a pulse from a Laser and of receiving the reflected light to measure the time-of-flight in order to determine the accurate range. The reflector is described. It is composed of a mosaic of fused quartz cube-corners, each about 1 inch across the face. The velocity aberration effect is considered to justify the use of a mosaic of small retroreflectors instead of fewer but larger ones. The satellite and the pulsed ruby Laser which NASA will use during the S-66 satellite's early life are described. The signals which might be expected in a typical situation are considered. The equipment which will be used shortly after the satellite is launched is presented. The real-time automatic digital optical tracker being developed for the acquisition of the satellite within the narrow Laser beam over a full 24 hours is studied.

231. Poehls, V. J.,
THE ATLANTIC MISSILE RANGE GLOBAL TRACKING SYSTEM, in 8th International Convention on Military Electronics, Conference, Proceedings, Washington D. C., 14-16 September 1964, Conference sponsored by the Military Electronics Group of the Institute of Electrical and Electronics Engineers, North Hollywood, Western Periodicals Company, 1964, pp. 103-106, A64-26750.

This is a description of a hardware/software complex known as GLOTRAC which is said to have a worldwide capability for providing measurement data on space launch and satellite vehicles. The hardware portion of the total system consists of the data-acquisition and data-processing systems and the software portion consists of the technical and scientific know-how required to operate and maintain the complex equipment. GLOTRAC was reportedly designed and produced under the direction of the USAF and is composed of pulse radars, CW radars, airborne transponders, and digital data-processing equipment. Equipment is currently installed at Cape Kennedy, Atlantic (North Carolina), Bermuda, San Salvador, Grand Turk, and Antigua. This group of stations is known as Segment 1. The San Salvador and Antigua stations use pulse radar in addition to the CW radars that are used at all stations. Segments 2, 3, 4, and 5, which encompass the globe, were planned to obtain measurement data on a multiple-burn vehicle that places satellites into synchronous (24-hour) orbits. The hardware for these segments is reported to be essentially complete, but AMR program requirements have redirected installation. The Segment 1 stations have recently tracked Atlas-Mercury and Atlas-Centaur launches.

232. Pressey, B. G.,
GROUND EQUIPMENT FOR RADIO OBSERVATIONS ON ARTIFICIAL SATELLITES, British Interplanetary Society Journal, Vol. 18, pp. 20-27, January-February 1961, A61-4736, (Symposium on Rocket and Satellite Instrumentation, London, England, 1 September 1960).

This is a description of the equipment and methods used at the Radio Research Station of the British Department of Scientific and Industrial Research. The observations have three purposes: (1) to obtain satellite position information, (2) to obtain data from the instruments in the satellite, and (3) to study the propagation of waves transmitted by the satellite. Radio interferometers operating on 20, 40, and 108 megacycles, and their operation are described. Methods used in analyzing signals from U. S. and Russian satellites are discussed, and the manner in which the observations can be used to study wave propagation is indicated.

233. Prim, D. C. and Lawhead, L. N.,
PREDICTED PERFORMANCE, GLOBAL TRACKING NETWORK AT AMR, in 10th Annual East Coast Conference on Aerospace and Navigational Electronics, Proceedings, Baltimore, Maryland, 21-23 October 1963, Conference sponsored by the Baltimore Section of the Institute of Electrical and Electronics Engineers and the Professional Technical Group on Aerospace and Navigational Electronics, North Hollywood, Western Periodicals Company, 1963, pp. 2.3.2-1 to 2.3.2-11, A64-18289.

This is a description of the major elements of the GLOTRAC Global Tracking network, and brief discussion of their individual capabilities. The performance of ground stations assigned to Segment 1 of the Atlantic Missile Range (AMR) is examined, based on computer simulations and on an informal tracking test in connection with the MA-9 Mercury launch. Considerations regarding the growth of GLOTRAC to an integrated tracking, telecommunications, command and control system are presented. It is concluded that GLOTRAC stations could be installed in Stable Ocean Platform (STOP) vessels or ships stationed to provide optimum multilateration solutions in regions where natural land masses do not exist. It is stated that a large scale investigation of the properties of the STOP vessel has been supported, and a configuration for possible range use has been accomplished.

234. Quigley, William W.,
GEMINI RENDEZVOUS RADAR, American Institute of Aeronautics and Astronautics, Guidance and Control Conference, Cambridge, Massachusetts, Paper 63-350, 8 pp., 12-14 August 1963, A63-21604.

This is a description of current radar for the Project Gemini rendezvous mission and its historical background. The reasons for selecting the transponder-augmented pulsed radar, using pulse round-trip-time for range measurement and interferometer techniques for angle measurement, are presented. The design techniques which have been implemented to give an accurate, highly reliable, lightweight system are described in detail. Block diagrams are presented of the interrogator radar and the transponder.

235. Radio Corporation of America, Moorestown, New Jersey,
TRADEX INSTRUMENTATION RADAR, February 1963, Contract No. DA 36-034-ORD-3063, AD-409 324.

The report summarizes the over-all Tradex Instrumentation Radar program and outlines the system design philosophy and concepts. RCA success in fulfilling these concepts is reflected in descriptions of Tradex radar techniques, system operation, and radar subsystems. Data, obtained during the system checkout program by the Tradex radar tracking ICBM satellites, and the Moon, is presented and analyzed. The system checkout tests provided preliminary indications of radar performance parameters such as tracking accuracy and precision, and range and Doppler resolution. Additional data and analysis will be required in the future to render completely definitive parameters. However, these tracking tests performed demonstrated the high capability of the Tradex radar to acquire and skin track small cross-section targets at long ranges, and to obtain parametric and phenomenological information on all targets in the radar beam at both UHF and L-band frequencies.

236. Richards, P. B.,
ORBIT DETERMINATION OF A NON-TRANSMITTING SATELLITE USING DOPPLER TRACKING DATA, IAS-ARS, Joint National Meeting, Los Angeles, California, Paper 61-141-1835, 22 pp., 13-16 June 1961, A61-6784.

This is an army-supported presentation of a method for predicting the orbit of a passive satellite, using exclusively Doppler data collected during one passage of the satellite by a tracking system consisting of only one transmitter and one receiver. Equations are derived which relate passive satellite Doppler tracking data to range, speed, and time parameters at closest approach. These determine an ellipsoid whose foci are the transmitter and receiver stations. The satellite lies on this ellipsoid, and its trajectory is tangent to the surface. Satellite position and velocity components at closest approach are calculated on a digital computer using information contained in the Doppler data together with the geometry of the tracking system. Preliminary orbits determined in this way are shown to agree favorably with the refined orbits of the Ballistic Research Laboratories.

237. Shklovskii, I. S.,
OPTICAL METHODS FOR TRACKING EARTH SATELLITES, (Iskusstvennye Sputniki Zemli, No. 1, 1958, p. 44), Planetary and Space Science, Vol. 5, pp. 233-237, July 1961, A61-8719 (Translation).

This is a discussion of optical methods for determining satellite space coordinates. It is shown that although optical tracking is limited to twilight conditions and is affected by the weather, it still affords an efficient means of precise tracking.

238. Space Technology Laboratories, Incorporated, Los Angeles, California,
SPACE SURVEILLANCE SYSTEMS, by W. D. Young, August 1961, Report No. BSD-TN-61-14, Contract No. AF 04(647)-302, AD-405 511.

Receiving and recording equipment for satellite and space probe tracking on a wide range of radio frequencies has been installed at the Nuffield Radio Astronomical Observatory, Jodrell Bank;

Cheshire, England. Installation was performed early in the summer of 1961 as the result of the combined efforts of the USAF Space Systems Division of Air Force Systems Command and the Space Technology Laboratories. This report describes the equipment installed and the work performed during the installation.

239. Spiglanin, Edward,
A TIMING AND SYNCHRONIZING SYSTEM FOR OPTICAL TRACKING, Automatic Control, Vol. 18, pp. 26-31, May 1963, A63-21323.

This is a description of a ballistic camera synchronization system used for the optical tracking of satellites. A block diagram and specifications of the system are given, and its principles of operation are described. One mode of system operation provides optical data information for system analysis, and the other mode is performed as a spatial calibration for the data runs taken in the divider type of operation.

240. System Development Corporation, Santa Monica, California,
AUGMENTED SATELLITE CONTROL FACILITY SYSTEM DESCRIPTION, by S. Weems, February 1963, Contract No. AF 19(625)-1648, AD-404 800.

The description of the augmented satellite control facility (SCF) is approached from two points of view: (1) the equipment subsystems are described in terms of their capabilities, functions, and primary usages; and (2) the principal activities performed by the SCF; i. e., telemetry, tracking, commanding, and scheduling are explained in such a way that the previously described equipments are tied together into systems, with emphasis on the functional aspects of SCF operations. The SCF is composed of a central control station, called the satellite test center (STC), and six remote tracking stations, three of which have limited dual capability. The STC is equipped to support six satellites simultaneously. Its data processing subsystems are divided into two main functional groupings: (1) the 'bird buffer complex' is vehicle oriented, and has eight CDC 160A computers, each of which can be individually assigned to an active satellite as a buffer; and (2) the off-line-computer complex, which uses four CDC 1604 computers to do the main computational chores for the system.

241. System Development Corporation, Santa Monica, California, FLIGHT SPECIFIC COMPUTER PROGRAM DESCRIPTION ALARM CLOCK (ALACK) MILESTONE 11, by D. J. Persico, January 1963, Contract No. AF 19 (628)-1648, AD-402 209.

This report presents computer programming for satellite position computations at specific time increments after acquisition by the several stations in a tracking network.

242. System Development Corporation, Santa Monica, California, SCF COMPUTER PROGRAM SYSTEMS MANUAL GENERAL PURPOSE SATELLITE PROGRAMS COMPUTE SATELLITE POSITION IN CARTESIAN COORDINATES (CARTES), by Lavine, January 1963, Contract No. AF 19 (628)-1648, AD-401 462.

This report presents computer use in recording satellite position in Cartesian coordinates.

243. Stockwell, E. J.,
SPACECRAFT TRACKING AND DATA ACQUISITION, American Geophysical Union, Transactions, IG Bulletin, Vol. 44, pp. 685-691, June 1963, A63-19983, (International Union of Geodesy and Geophysics, 13th General Assembly, United States National Report, 1960-1963).

This is a brief description of tracking station networks which satisfactorily support the wide variety of NASA space exploration efforts now underway. Outlined are the methods of tracking, command, data acquisition, and data handling and display for (a) the Minitrack Earth Satellite Network, used primarily for support of the unmanned scientific satellite program, and comprising 13 stations throughout the world; (b) the Baker-Nunn Camera Network, each station of which is equipped with a Baker-Nunn camera specially designed for the photographic tracking of artificial Earth satellites; (c) the Manned Space Network, which communicates with the spacecraft from lift-off to touchdown from 17 locations; and (d) the Deep Space Network.

244. Stodola, E. K.,
RADAR FOR SATELLITE TRACKING, Missiles and Space, pp. 16-19 and 41, June 1962, A62-8346.

This is a description of the Very Long Range Tracking (VERLORT) radar system, which incorporates a novel ranging system for tracking to extreme distances with relatively high pulse repetition rates. The system also incorporates communication capabilities and can, in some cases, become part of the guidance loop. Pulse traces and timing diagrams are presented, as is a table showing the range capability of the 3000 megacycles per second system and an attenuation versus range curve for isotropic-antenna operation.

245. Veis, George,
THE PRECISION OPTICAL SATELLITE TRACKING NET OF THE SMITHSONIAN ASTROPHYSICAL OBSERVATORY, in The Use of Artificial Satellites for Geodesy, Proceedings of the 1st International Symposium on the Use of Artificial Satellites for Geodesy, Washington, D. C., 26-28 April 1962, Committee on Space Research (COSPAR), International Union of Geodesy and Geophysics, and UNESCO, Amsterdam, Holland, North-Holland Publishing Company; New York, Interscience Publishers Division, John Wiley and Sons, Incorporated, 1963, pp. 141-145, A63-24717.

This is a brief description of the operation of the precision optical tracking net operated by the Smithsonian Astrophysical Observatory. The net consists of 12 stations capable of determining photographically the direction of most satellites with an accuracy of ± 2 inches of arc in topocentric position and ± 1 millisecond in time.

246. Viterbi, Andrew J.,
PHASE-LOCK-LOOP SYSTEMS, in SPACE COMMUNICATIONS, New York, McGraw-Hill Book Company, Incorporated, 1963, pp. 123-142, A64-11237.

This presents a general discussion of the principles and applications of phase-lock loop, or automatic phase-control circuit, used on missiles, satellites, and space probes, for tracking relatively narrowband signals coherently in a high-noise environment. The basic operation and phase-locking behavior of the loop are delineated, and its performance in the presence of additive noise is described. Tracking and telemetry applications are discussed.

247. Vitkevich, V. V., Kuz'min, A. D., Matveenko, L. I., Sorochenko, R. L., and Udal'tsov, V. A.,
RADIOASTRONOMICHESKIE NABLIUDENIIA SOVETSKIKH KOSMICHESKIKH RAKET, Radiotekhnika i Elektronika, Vol. 6, pp. 1420-1431, September 1961, A62-977 (In Russian).

This is a description of the use of the radiointerferential method in tracking the first three Soviet cosmic rockets. The basic relationships of the method are defined, and the equipment and method of alignment according to discrete radio sources are described. The coordinates and time of lunar landing of the instrument capsule are determined.

248. Weiss, H. G.,
THE HAYSTACK MICROWAVE RESEARCH FACILITY, IEEE Spectrum, Vol. 2, pp. 50-69, February 1965, A65-16896.

This presents a description of a new microwave communications facility. Haystack is a multipurpose facility, designed to operate as a versatile ground terminal for satellite, space communication, and radio propagation experiments, as a powerful tracking and measurements radar, and as a sensitive, high-resolution radio telescope. In each of these applications, the Haystack has a performance capability superior to that of any existing microwave facility. It is distinguished by the facts that: (1) a metal-space-frame radome is employed for the first time in a low-noise microwave system, (2) improved techniques have been developed which now make it possible to analyze and predict the behavior of a complex space-frame and shell structures with an uncertainty of only one part in 100, 000, (3) a precision optical surveying means has been integrated into the antenna to enable surface contour to be measured at any desired orientation angle, (4) an unusual hydrostatic bearing has been developed which has low static friction and permits the positioning and control of the antenna with great precision, (5) the on-line use of a digital computer in the antenna control system enables an unskilled operator to utilize the antenna in an efficient and flexible manner, and (6) the integration of a "plug-in" equipment room within the antenna structure and a versatile system of interconnecting cables make it possible to employ the facility for many different applications. Initial testing and operation of the Haystack facility provide assurance that the objectives of the development program have been achieved.

249. Wolf Research and Development Corporation, West Concord, Massachusetts,
CAION SATELLITE SYSTEM STUDY, November 1963, Report No. AFCRL-63-920, Contract No. AF 19(628)-3258, AD-426 799.

This report summarizes the results of a study program conducted on the primary features of a calibration satellite system for the calibration of the AMR tracking instrumentation. It considers the general requirements for the satellite, booster, tracking stations, ground station equipment, as well as all operational requirements including digital computer programs and data links necessary to effect a calibration. The major study areas covered include planning studies, calibration ground system studies, orbit and trajectory studies, and satellite equipment studies. Recommendations for future efforts are also provided.

250. Woodard, David J. and DeBold, Joseph F., USNS KINGSPORT - SATELLITE COMMUNICATIONS SHIP, American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D. C., Paper 64-417, 12 pp., 29 June-2 July 1964, A64-21042.

This presents a brief description of the equipment and methods employed aboard the USNS Kingsport, a ship specifically equipped to track, control, and communicate via satellites. The modifications in the original vessel (launched in 1944) and the personnel training necessary to provide the ship with the capability for its missions are delineated, and equipment comprising the five major subsystems - antenna, communications, telemetry and command, range and range rate, and computer - is outlined. The Syncom satellites and flight plans are briefly reviewed, and the role of the Kingsport in Syncom satellite tracking is described, including the solution to problems encountered during early stages of operations. The advantages of a mobile satellite communications facility in peace and war are noted.

251. Woods, Calvin R., AN ACCURATE SHIPBOARD RADIO TRACKING SYSTEM, in Space Technology and Science, 5th International Symposium, Proceedings, Tokyo, Japan, 2-7 September 1963 (A65-14290 05-31), Tokyo, Japan, AGNE Corporation, 1964, pp. 861-872, A65-14358.

This is a description of a radio tracking system based on a ship, and prediction of its performance by an error analysis. It is stated that the system using synchronous satellites can locate a shipboard tracking system with sufficient accuracy to enable the system to provide useful tracking. Once the satellites are available for use, the tracking ships can be set up at almost any location on Earth and on short notice. One limitation is that the ships must not be within about 5 degrees of the equator, or else large errors will result. This could be countered by causing the satellite orbits to have 5 or 10 degrees inclination. It is pointed out that perhaps the largest cost of such a system would be the cost of the satellites themselves. However, it is likely that synchronous satellites will be placed into orbit for other reasons, and these might be shared by the tracking system. The equipment required aboard the satellite for the tracking system would be a simple transponder that would weigh from 5 to 10 pounds, and which would only need to be turned on when needed. The power required would be in the order of 50 watts. This transponder might also be shared; for example, it might be used for tracking the satellite from a ground station to determine its ephemeris or to correct its orbit.

252. Woods, Calvin R. and Mullen, E. B.,
PRECISION TRACKING OF SPACE VEHICLES, ARS Guidance, Control and Navigation Conference, Stanford, California, Preprint 1938-61, 26 pp., 7-9 August 1961, A62-2064.

This is a NASA-supported study of the theory, operation, and application of precision radio tracking systems. It is shown that by the use of long-baseline techniques, accuracies in position and velocity measurements rivaling good optical systems can be obtained. An analysis is made of the ability of such systems to measure the effects in the orbit of a satellite of the fine-grained structure of the Earth's gravitational field. A second example treats the tracking of a synchronous satellite and derives the errors in measured drift rate as a function of observation time.

253. Wye, R. E., Teicher, S., Kellar, W. J., and Blum, B.,
SPACECRAFT TRACKING AND DATA ACQUISITION, in 2nd Manned Space Flight Meeting, New York, American Institute of Aeronautics and Astronautics, 1963, pp. 206-212, A63-19009.

This is a brief review of the factors involved in tracking-data acquisition. The effect of various errors on the technique used in determining the trajectory is considered, including the uncertainties in the speed of light, station location, and atmospheric density. It is seen that the unknowns in nature, and a lack of knowledge of the shape of the Earth, restrict the accuracy to which a spacecraft position can be predicted. The merits of various types of tracking are discussed in terms of altitude and coverage. A table lists some tracking-system characteristics, including those for the AN/FPS-16, AN/FPQ-6, VERLORT, IIR, Range-Range Rate, JPL PN Ranging, and Azusa MKII. The acquisition of the spacecraft signals that are to be used in computing its position, and the frequency-time acquisition problem are also considered.

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None	Same as No. 1

13. ABSTRACT

The cited references pertain to the area of "Satellite Orbit Determination." This bibliography covers the following: (1) Methods to use and combine tracking data from radar and other tracking systems for orbit determination, and (2) The influence of tracking station location, number of stations, and time of tracking on the accuracy of orbit determination.

In addition to the above, the cited references cover analysis and simulation of orbits; mathematics and parameters of orbits; theory and techniques; prediction and accuracies; programming and computers; error analysis; evaluation of ground coverage; systematic errors; airborne platforms; space dynamics; self-contained orbit determination techniques; and space-time.

This bibliography consists of four sections:

Section I - Introduction.

Section II - Orbit Determination, Entries 1 through 161.

Section III - Programs and Satellite Systems, Entries 162 through 187.

Section IV - Equipment and Facilities for Orbit Determination, Earth-Based, Entries 188 through 253.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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